PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 :
B81B 3/00, 7/02, B81C 1/00, B41J 2/045, 2/14, 2/16

A1

(11) International Publication Number: WO 00/48938

(43) International Publication Date: 24 August 2000 (24.08.00)

(21) International Application Number: PCT/AU00/00095

(22) International Filing Date: 11 February 2000 (11.02.00)

(30) Priority Data:

PP 8686	15 February 1999 (15.02.99)	AU
PP 8687	15 February 1999 (15.02.99)	AU
PP 8688	15 February 1999 (15.02.99)	AU
PP 8689	15 February 1999 (15.02.99)	AU
PP 8690	15 February 1999 (15.02.99)	AU
PP 8691	15 February 1999 (15.02.99)	AU

(71) Applicant *(for all designated States except US)*: SILVERBROOK RESEARCH PTY LTD [AU/AU]; 393 Darling Street, Balmain, NSW 2041 (AU).

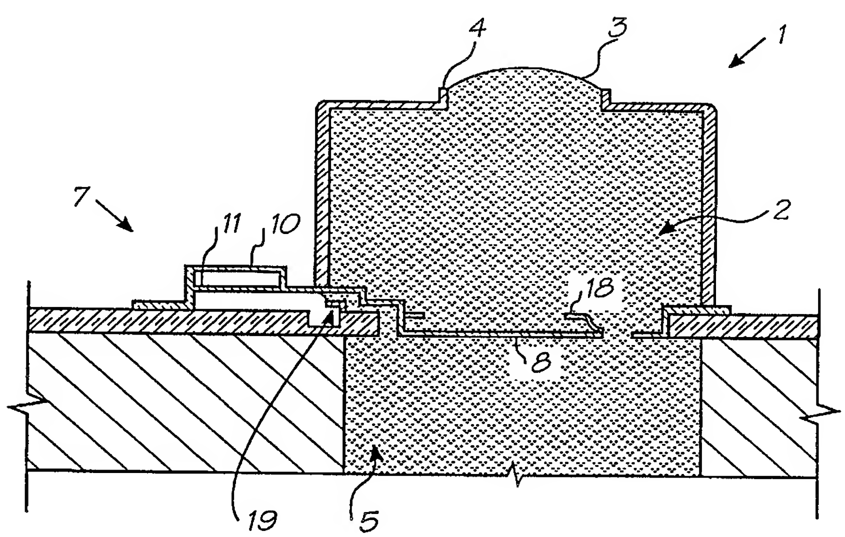
(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: SILVERBROOK, Kia [AU/AU]; 214 Catherine Street, Leichhardt, NSW 2040 (AU).

(74) Agent: SILVERBROOK RESEARCH PTY. LTD.; 393 Darling Street, Balmain, NSW 2041 (AU).

(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: THERMAL BEND ACTUATOR AND PADDLE STRUCTURE FOR INK JET NOZZLE



(57) Abstract

A thermal actuator (7) for micro electromechanical systems (MEMS) comprises two arms (10, 11), with a gap between them for improving operational characteristics and reducing shear stress, where one arm is arranged to undergo thermal expansion to cause the actuator to bend. The actuator (7) may be used to operate a paddle (8) for an ink jet nozzle chamber (2). An aperture in the nozzle chamber (2) has a raised rim (19) for forming a meniscus with the actuator (7), for preventing leakage from the nozzle chamber (2). The paddle (8) has a structural support portion (18) which acts as a spacer to prevent contact between the paddle (8) and a meniscus (3) at the nozzle (4). The nozzle chamber (2) has an internal protrusion, aligned with and opposite to the paddle (8) in its non–ejection state, which aids rapid refill of the nozzle chamber (2) after ejection.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	**ES**	Spain	**LS**	Lesotho	**SI**	Slovenia
AM	Armenia	**FI**	Finland	**LT**	Lithuania	**SK**	Slovakia
AT	Austria	**FR**	France	**LU**	Luxembourg	**SN**	Senegal
AU	Australia	**GA**	Gabon	**LV**	Latvia	**SZ**	Swaziland
AZ	Azerbaijan	**GB**	United Kingdom	**MC**	Monaco	**TD**	Chad
BA	Bosnia and Herzegovina	**GE**	Georgia	**MD**	Republic of Moldova	**TG**	Togo
BB	Barbados	**GH**	Ghana	**MG**	Madagascar	**TJ**	Tajikistan
BE	Belgium	**GN**	Guinea	**MK**	The former Yugoslav Republic of Macedonia	**TM**	Turkmenistan
BF	Burkina Faso	**GR**	Greece	**ML**	Mali	**TR**	Turkey
BG	Bulgaria	**HU**	Hungary	**MN**	Mongolia	**TT**	Trinidad and Tobago
BJ	Benin	**IE**	Ireland	**MR**	Mauritania	**UA**	Ukraine
BR	Brazil	**IL**	Israel	**MW**	Malawi	**UG**	Uganda
BY	Belarus	**IS**	Iceland	**MX**	Mexico	**US**	United States of America
CA	Canada	**IT**	Italy	**NE**	Niger	**UZ**	Uzbekistan
CF	Central African Republic	**JP**	Japan	**NL**	Netherlands	**VN**	Viet Nam
CG	Congo	**KE**	Kenya	**NO**	Norway	**YU**	Yugoslavia
CH	Switzerland	**KG**	Kyrgyzstan	**NZ**	New Zealand	**ZW**	Zimbabwe
CI	Côte d'Ivoire	**KP**	Democratic People's Republic of Korea	**PL**	Poland		
CM	Cameroon	**KR**	Republic of Korea	**PT**	Portugal		
CN	China	**KZ**	Kazakstan	**RO**	Romania		
CU	Cuba	**LC**	Saint Lucia	**RU**	Russian Federation		
CZ	Czech Republic	**LI**	Liechtenstein	**SD**	Sudan		
DE	Germany	**LK**	Sri Lanka	**SE**	Sweden		
DK	Denmark	**LR**	Liberia	**SG**	Singapore		
EE	Estonia						

THERMAL BEND ACTUATOR AND PADDLE STRUCTURE FOR INK JET NOZZLE

Field of the Invention

The present invention relates to the field of micro mechanical or micro electro-mechanical devices such as ink jet printers. The present invention will be described herein with reference to Micro Electro Mechanical Inkjet technology. However, it will be appreciated that the invention does have broader applications to other micro mechanical or micro electromechanical devices, e.g. micro electromechanical pumps or micro electromechanical movers.

Background of the Invention

Micro mechanical and micro electromechanical devices are becoming increasingly popular and normally involve the creation of devices on the µm (micron) scale utilizing semi-conductor fabrication techniques. For a recent review on micro-mechanical devices, reference is made to the article "The Broad Sweep of Integrated Micro Systems" by S. Tom Picraux and Paul J. McWhorter published December 1998 in IEEE Spectrum at pages 24 to 33.

One form of micro electro-mechanical devices in popular use are ink jet printing devices in which ink is ejected from an ink ejection nozzle chamber. Many forms of ink jet devices are known.

Many different techniques on ink jet printing and associated devices have been invented. For a survey of the field, reference is made to an article by J Moore, "Non-Impact Printing: Introduction and Historical Perspective", Output Hard Copy Devices, Editors R Dubeck and S Sherr, pages 207 to 220 (1988).

Recently, a new form of ink jet printing has been developed by the present applicant, which is referred to as Micro Electro Mechanical Inkjet (MEMJET) technology. In one form of the MEMJET technology, ink is ejected from an ink ejection nozzle chamber utilizing an electro mechanical actuator connected to a paddle or plunger which moves towards the ejection nozzle of the chamber for ejection of drops of ink from the ejection nozzle chamber.

The present invention concerns improvements to a mechanical bend actuator for use in the MEMJET technology or other micro mechanical or micro electro-mechanical devices.

Summary of the Invention

In accordance with a first aspect of the present invention, there is provided a thermal actuator for micro electro-mechanical devices, the actuator comprising a supporting substrate, an actuation portion, a first arm attached at a first end thereof to the substrate and at a second end to the actuation portion, the first arm being arranged, in use, to be conductively heatable, a second arm attached at a first end to the supporting substrate and at a second end to the actuation portion, the second arm being spaced apart from the first arm, whereby the first and second arm define a gap between them; and wherein, in use, the first arm is arranged to undergo thermal expansion when conductively heated, thereby causing a force to be applied to the actuation portion.

Accordingly, the operational characteristics of the actuator such as e.g. its operation temperature can be less dependent on a material of the actuation portion when compared with conventional thermal actuators. In conventional thermal actuators, the actuation portion is typically located, in part, between the arms of a thermal actuator (tri-layer actuator). Furthermore, if the actuation portion is located, in part, between the arms, shear stresses are, in use, induced in that part of the actuation portion, which can reduce the efficiency of the actuator.

The actuator may be arranged in a manner such that a heating current can be applied to the first arm through the supporting substrate.

The first and second arms are preferably formed from substantially the same material.

The actuator can be manufactured by the steps of: depositing and etching a first layer to form the first arm; depositing and etching a second layer to form a sacrificial layer supporting structure over the first arm; and depositing and etching a third layer to form the second arm, and etching the second layer to form the gap between the first and second arms.

The first arm can comprise two elongated flexible strips conductively interconnected at the second end.

The second arm can comprise two elongated flexible strips.

The actuation portion can comprise a paddle structure. Accordingly, the actuator may be used inside a liquid ejection chamber, the paddle structure being movable for the ejection of liquid from the chamber.

The first arm can be formed from titanium nitride and the second arm can also be formed from titanium nitride.

In accordance with a second aspect of the present invention there is disclosed a novel form of manufacture of an ink jet printing system.

In accordance with a third aspect of the present invention there is provided a paddle for ejecting liquid from within a nozzle chamber out through a liquid ejection nozzle defined in one wall of the nozzle chamber, the paddle comprising a first portion being configured to, in use, provide a substantially planar plunger surface opposite to and spaced apart from the nozzle, and a second portion formed on the plunger surface in the periphery of the first portion for providing structural support for the first portion, whereby, in use, during actuation of the plunger to eject liquid through the nozzle the second portion acts as a spacer preventing the plunger surface from reaching the nozzle.

Having the plunger surface spaced apart form the nozzle is important to reduce the likelihood of a meniscus of the liquid at the nozzle making contact with the plunger surface, which could affect the operational characteristics of such an arrangement. It will be appreciated by a person skilled in the art that accordingly the size of a chamber embodying the present invention can be reduced for the same ejection volume, when compared with a paddle having a constant thickness, previously thought to be required for structural soundness.

The second portion may be configured to define a continuous wall structure around a center portion of the plunger surface, the center portion, in use, being substantially aligned with the nozzle.

The center portion may preferably be of the same dimensions as the nozzle.

The first portion can have a circular circumference and the second portion can comprise an annulus around the circumference of the paddle.

The paddle can be substantially symmetrically arranged around the liquid ejection nozzle and can be formed by: depositing and etching a first layer to form the first paddle portion; depositing and etching a second layer to form a sacrificial layer supporting structure over the first paddle portion; and depositing and etching a third layer to from the third paddle portion.

In accordance with a fourth aspect of the present invention, there is provided a mechanical actuator for micro mechanical or micro electro-mechanical devices, the actuator comprising a supporting substrate, an actuation portion, a first arm attached at a first end thereof to the substrate and at a second end to the actuation portion, the first arm being arranged, in use, to be conductively heatable, a second arm attached at a first end to the supporting substrate and at a second end to the actuation portion, the second arm being spaced apart from the first arm, whereby the first and second arm define a gap between them, at least one rigid member interconnecting the first and second arms between the first and second ends thereof, and wherein, in use, the first arm is arranged to undergo expansion, thereby causing the actuator to apply a force to the actuation portion.

It has been found by the applicant that the provision of the rigid member between the first and second arms can prevent buckling of the arms when the first arm undergoes expansion.

The first arm preferably can comprise: a first main body formed between the first and second ends of the first arm; at least one tab body connected to the first main body; a first one of the at least one rigid members interconnecting the tab with the second arm.

The second arm preferably can comprise: a second main body formed between the first and second end of the second arm; at least one corresponding tab body connected to the second main body; the first one of the at least one rigid members interconnecting the corresponding tabs of the first and second arms.

The tab body may be connected to the first main body via a first thinned neck portion.

The corresponding tab body may be connected to the second main body via a second thinned neck portion.

The first arm can comprise a conductive layer whereby the first arm is conductively heatable to cause, in use, the first arm to undergo thermal expansion relative to the second arm thereby causing the actuator to apply a force to the actuation portion.

The first and second arms are preferably substantially parallel and the rigid member can be substantially perpendicular to the first and second arm.

The actuator may be arranged in a manner such that a current can be supplied to the conductive layer through the supporting substrate.

The first and second arm are preferably formed from substantially the same material.

The actuator can be manufactured by the steps of: depositing and etching a first layer to form the first arm; depositing and etching a second layer to form a sacrificial layer supporting structure over the first arm; depositing and etching a third layer to form the second arm, and etching the sacrificial layer to form the gap between the first and second arms.

The first arm can comprise two elongated flexible strips conductively interconnected at the second end. The second arm also can comprise two elongated flexible strips.

The actuation portion can comprise a paddle structure. Accordingly, the actuator may be used inside a liquid ejection chamber, the paddle structure being movable for the ejection of liquid from the chamber.

The first conductive arm can be formed from titanium nitride and the second arm can be formed from titanium nitride.

In accordance with a fifth aspect of the present invention, there is provided a thermal actuator for micro mechanical or micro electro-mechanical devices, the actuator comprising a supporting substrate, an actuator extension portion, a first arm attached at a first end thereof to the substrate and at a second end to the extension portion, the first arm being arranged, in use, to be conductively heatable, a second arm attached at a first end to the supporting substrate and at a second end to the extension portion, the second arm being spaced apart from the first arm, the first arm being arranged , in use, to undergo thermal expansion, thereby causing the actuator to apply a force to the extension portion, and wherein the first arm comprises at least one heat sink element substantially at a point of maximum heating of the first arm, being the point where, in use, maximum heating of the first arm would occur.

It has been found by the applicant that the provision of the heat sink element can improve the operational characteristics of the thermal bend actuator in that the maximum temperature in the first arm can be reduced, and in that a more uniform temperature profile can be achieved throughout the first arm. This can maximise the thermal expansion induced in the first arm.

The heat sink element can be located substantially in the middle of the first arm.

The heat sink element may be arranged to interconnect the first and second arm.

The heat sink element can comprise at least one tab body connected to a main body of the first arm.

The tab body may be connected to the main body via a first thinned neck portion.

The first arm can comprise a conductive layer whereby the first arm is conductively heatable.

The actuator may be arranged in a manner such that a current can be supplied to the conductive layer through the supporting substrate.

The first and second arms are preferably formed from substantially the same material.

The extension portion can comprise a paddle structure. Accordingly, the actuator may be used inside a liquid ejection chamber, the paddle structure being movable for the ejection of liquid from the chamber.

The first conductive arm can be formed from titanium nitride and the second arm can be formed from titanium nitride.

In accordance with a sixth aspect of the present invention, there is provided a liquid ejection device comprising: a nozzle chamber having a first aperture in one wall thereof for the ejection of the liquid and a second aperture in a wall thereof through which an actuator arm extends, the actuator arm being attached to a substrate located outside the nozzle chamber and being connected to a paddle inside the nozzle chamber, the paddle being operable by way of the actuator arm to eject the liquid through the first aperture; the system further comprising a first raised rim formed around the second aperture, the first raised rim being arranged in a manner such that, during operation of the actuator arm, a liquid meniscus is being formed along an outer surface of the liquid between the first raised rim and the actuator arm.

Accordingly, spreading of the liquid outside of the nozzle chamber through the second aperture may be prevented.

The actuator preferably can include a planar portion adjacent the first raised rim, the planar portion being generally parallel to and spaced apart from the substrate.

The first raised rim preferably can include an edge portion substantially parallel to the planar portion.

The first raised rim may comprise a raised lip.

The device may further comprise a second raised rim formed on the actuator arm adjacent the first raised rim formed around the second aperture. In this embodiment, the second raised rim may assist in the prevention of spreading of the liquid outside of the nozzle chamber through the second aperture.

The first raised rim can be formed from deposition of a layer which also forms a portion of the actuator arm.

At least on of the first and second raised rims can be formed from titanium nitride.

Adjacent the first raised rim there is preferably formed a pit to assist in reducing wicking.

In accordance with a seventh aspect of the present invention, there is provided a liquid ejection device comprising a nozzle chamber, an ejection paddle located within the nozzle chamber for ejecting liquid from the nozzle chamber though an aperture in one wall of the nozzle chamber when the paddle is moved from a first state into an ejection state, a liquid supply port arranged in a manner such that it is substantially closed by the paddle when the paddle is in the first state, and wherein the nozzle chamber comprises an internal protrusion on a wall structure thereof which is aligned closely adjacent to a rim of the paddle when the paddle is in the first state, and wherein, in the ejection state, at least a portion of the rim of the paddle is spaced apart from the protrusion, thereby forming a liquid refill channel defined between the wall structure and the portion of the rim of the paddle.

The internal protrusion may have a staircase-like cross-sectional profile.

The paddle and the internal protrusion are preferably formed in one deposition step.

The internal protrusion may be formed using a lower aspect ratio deposition step when compared to a high aspect ratio deposition step for forming the wall structure of the nozzle chamber.

The paddle may be substantially planar.

Brief Description of the Drawings

Notwithstanding any other forms which may fall within the scope of the present invention, preferred forms of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 to Fig. 3 illustrate schematically the operation of the preferred embodiment;

Fig. 4 to Fig. 6 illustrate schematically a first thermal bend actuator;

Fig. 7 to Fig. 8 illustrate schematically a second thermal bend actuator;

Fig. 9 to Fig. 10 illustrate schematically a third thermal bend actuator;

Fig. 11 illustrates schematically a further thermal bend actuator;

Fig. 12 illustrates an example graph of temperature with respect to distance for the arrangement of Fig. 11;

Fig. 13 illustrates schematically a further thermal bend actuator;

Fig. 14 illustrates an example graph of temperature with respect to distance for the arrangement of Fig. 13;

Fig. 15 illustrates schematically a further thermal bend actuator;

Fig. 16 illustrates a side perspective view of the CMOS layer of the preferred embodiment;

Fig. 17 illustrates a 1 micron mask;

Fig. 18 illustrates a plan view of a portion of the CMOS layer;

Fig. 19 illustrates a side perspective view of the preferred embodiment with the sacrificial Polyimide Layer;

Fig. 20 illustrates a plan view of the sacrificial Polyimide mask;

Fig. 21 illustrates a side plan view, partly in section, of the preferred embodiment with the sacrificial Polyimide Layer;

Fig. 22 illustrates a side perspective view of the preferred embodiment with the first level Titanium Nitride Layer;

Fig. 23 illustrates a plan view of the first level Titanium Nitride mask;

Fig. 24 illustrates a side plan view, partly in section, of the preferred embodiment with the first level Titanium Nitride Layer;

Fig. 25 illustrates a side perspective view of the preferred embodiment with the second level sacrificial Polyimide Layer;

Fig. 26 illustrates a plan view of the second level sacrificial Polyimide mask;

Fig. 27 illustrates a side plan view, partly in section, of the preferred embodiment with the second level sacrificial Polyimide Layer;

Fig. 28 illustrates a side perspective view of the preferred embodiment with the second level Titanium Nitride Layer;

Fig. 29 illustrates a plan view of the second level Titanium Nitride mask;

Fig. 30 illustrates a side plan view, partly in section, of the preferred embodiment with the second level Titanium Nitride Layer;

Fig. 31 illustrates a side perspective view of the preferred embodiment with the third level sacrificial Polyimide Layer;

Fig. 32 illustrates a plan view of the third level sacrificial Polyimide mask;

Fig. 33 illustrates a side plan view, partly in section, of the preferred embodiment with the third level sacrificial Polyimide Layer;

Fig. 34 illustrates a side perspective view of the preferred embodiment with the conferral PECVD SiNH Layer;

Fig. 35 illustrates a plan view of the conformal PECVD SiNH mask;

Fig. 36 illustrates a side plan view, partly in section, of the preferred embodiment with the conformal PECVD SiNH Layer;

Fig. 37 illustrates a side perspective view of the preferred embodiment with the conformal PECVD SiNH nozzle tip etch Layer;

Fig. 38 illustrates a plan view of the conferral PECVD SiNH nozzle tip etch mask;

Fig. 39 illustrates a side plan view, partly in section, of the preferred embodiment with the conformal PECVD SiNH nozzle tip etch Layer;

Fig. 40 illustrates a side perspective view of the preferred embodiment with the conformal PECVD SiNH nozzle roof etch Layer;

Fig. 41 illustrates a plan view of the conformal PECVD SiNH nozzle roof etch mask;

Fig. 42 illustrates a side plan view, partly in section, of the preferred embodiment with the conformal PECVD SiNH nozzle roof etch Layer;

Fig. 43 illustrates a side perspective view of the preferred embodiment with the sacrificial protective polyimide Layer;

Fig. 44 illustrates a plan view of the sacrificial protective polyimide mask;

Fig. 45 illustrates a side plan view, partly in section, of the preferred embodiment with the sacrificial protective polyimide Layer;

Fig. 46 illustrates a side perspective view of the preferred embodiment with the back etch Layer;

Fig. 47 illustrates a plan view of the back etch mask;

Fig. 48 illustrates a side plan view, partly in section, of the preferred embodiment with the back etch Layer;

Fig. 49 illustrates a side perspective view of the preferred embodiment with the stripping sacrificial material Layer;

Fig. 50 illustrates a plan view of the stripping sacrificial material mask;

Fig. 51 illustrates a side plan view, partly in section, of the preferred embodiment with the stripping sacrificial material Layer;

Fig. 53 illustrates a plan view of the package, bond, prime and test mask;

Fig. 54 illustrates a side plan view, partly in section, of the preferred embodiment with the package, bond, prime and test;

Fig. 55 illustrates a side perspective view in section of the preferred embodiment ejecting a drop;

Fig. 56 illustrates a side perspective view of the preferred embodiment when actuating;

Fig. 57 illustrates a side perspective view in section of the preferred embodiment ejecting a drop;

Fig. 58 illustrates a side plan view, partly in section, of the preferred embodiment when returning;

Fig. 59 illustrates a top plan view of the preferred embodiment;

Fig. 60 illustrates an enlarged side perspective view showing the actuator arm and nozzle chamber;

Fig. 61 illustrates an enlarged side perspective view showing the actuator paddle rim and nozzle chamber;

Fig. 62 illustrates an enlarged side perspective view showing the actuator heater element;

Fig. 63 illustrates a top plan view of an array of nozzles formed on a wafer;

Fig. 64 illustrates a side perspective view in section of an array of nozzles formed on a wafer; and

Fig. 65 illustrates an enlarged side perspective view in section of an array of nozzles formed on a wafer.

Description of Preferred and Other Embodiments

In the preferred embodiment, a compact form of liquid ejection device is provided which utilizes a thermal bend actuator to eject ink from a nozzle chamber.

Turning initially to Fig. 1 - 3 there will now be explained the operational principals of the preferred embodiment. As shown in Fig. 1, there is provided an ink ejection arrangement 1 which comprises a nozzle chamber 2 which is normally filled with ink so as to form a meniscus 3 around an ink ejection nozzle 4 having a raised rim. The ink within the nozzle chamber 2 is resupplied by means of ink supply channel 5.

The ink is ejected from a nozzle chamber 2 by means of a thermal actuator 7 which is rigidly interconnected to a nozzle paddle 8. The thermal actuator 7 comprises two arms 10, 11 with the bottom arm 11 being interconnected to a electrical current source so as to provide conductive heating of the bottom arm 11. When it is desired to eject a drop from the nozzle chamber 2, the bottom arm 11 is heated so as to cause the rapid expansion of this arm 11 relative to the top arm 10. The rapid expansion in turn causes a rapid upward movement of the paddle 8 within the nozzle chamber 2. The initial movement is illustrated in Fig. 2 with the arm 8 having moved upwards so as to cause a substantial increase in pressure within the nozzle chamber 2 which in turn causes ink to flow out of the nozzle 4 causing the meniscus 3 to bulge. Subsequently, the current to the heater 11 is turned off so as to cause the paddle 8 as shown in Fig. 3 to begin to return to its original position. This results in a substantial decrease in the pressure within the nozzle chamber 2. The forward momentum of the ink outside the nozzle rim 4 results in a necking and breaking of the meniscus so as to form meniscus 3 and a bubble 13 as illustrated in Fig. 3. The bubble 13 continues forward onto the ink print medium.

Importantly, the nozzle chamber comprises a profile edge 15 which, as the paddle 8 moves up, causes a large increase in the channel space 16 as illustrated in Fig. 2. This large channel space 16 allows for substantial amounts of ink to flow rapidly into the nozzle chamber 2 with the ink being drawn through the channel 16 by means of surface tension effects of the ink meniscus 3. The profiling of the nozzle chamber

allows for the rapid refill of the nozzle chamber with the arrangement eventually returning to the quiescent position as previously illustrated in Fig. 1.

The arrangement 1 also comprises a number of other significant features. These comprise a circular rim 18, as shown in Fig. 1 which is formed around an external circumference of the paddle 8 and provides for structural support for the paddle 8 whilst substantially maximising the distance between the meniscus 3, as illustrated in Fig. 3 and the paddle surface 8. The maximising of this distance reduces the likelihood of meniscus 3 making contact with the paddle surface 8 and thereby affecting the operational characteristic. Further, as part of the manufacturing steps, an ink outflow prevention lip 19 is provided for reducing the possibility of ink wicking along a surface eg. 20 and thereby affecting the operational characteristics of the arrangement 1.

The principals of operation of the thermal actuator 7 will now be discussed initially with reference to Fig. 4 to 10. Turning initially to Fig. 4, there is shown, a thermal bend actuator attached to a substrate 22 which comprises an actuator arm 23 on both sides of which are activating arms 24, 25. The two arms 24, 25 are preferably formed from the same material so as to be in a thermal balance with one another. Further, a pressure P is assumed to act on the surface of the actuator arm 23. When it is desired to increase the pressure, as illustrated in Fig. 5, the bottom arm 25 is heated so as to reduce the tensile stress between the top and bottom arm 24, 25. This results in an output resultant force on the actuator arm 23 which results in its general upward movement.

Unfortunately, it has been found in practice that, if the arms 24, 25 are too long, then the system is in danger of entering a buckling state as illustrated in Fig. 6 upon heating of the arm 25. This buckling state reduces the operational effectiveness of the actuator arm 23. The opportunity for the buckling state as illustrated in Fig. 6 can be substantially reduced through the utilisation of a smaller thermal bending arms 24, 25 with the modified arrangement being as illustrated in Fig. 7. It is found that, when heating the lower thermal arm 25 as illustrated in Fig. 8, the actuator arm 23 bends in a upward direction and the possibility for the system to enter the buckling state of Fig. 6 is substantially reduced.

In the arrangement of Fig. 8, the portion 26 of the actuator arm 23 between the activating portion 24, 25 will be in a state of shear stress and, as a result, efficiencies of

operation may be lost in this embodiment. Further, the presence of the material 26 can resulted in rapid thermal conductivity from the arm portion 25 to the arm portion 24.

Further, the thermal arm 25 must be operated at a temperature which is suitable for operating the arm 23. Hence, the operational characteristics are limited by the characteristics, eg. melting point, of the portion 26.

In Fig. 9, there is illustrated an alternative form of thermal bend actuator which comprises the two arms 24, 25 and actuator arm 23 but wherein there is provided a space or gap 28 between the arms. Upon heating one of the arms, as illustrated in Fig. 10, the arm 25 bends upward as before. The arrangement of Fig. 10 has the advantage that the operational characteristics eg. temperature, of the arms 24, 25 may not necessarily be limited by the material utilized in the arm 23. Further, the arrangement of Fig. 10 does not induce a sheer force in the arm 23 and also has a lower probability of delaminating during operation. These principals are utilized in the thermal bend actuator of the arrangement of Fig. 1 to Fig. 3 so as to provide for a more energy efficient form of operation.

Further, in order to provide an even more efficient form of operation of the thermal actuator a number of further refinements are undertaken. A thermal actuator relies on conductive heating and, the arrangement utilized in the preferred embodiment can be schematically simplified as illustrated in Fig. 11 to a material 30 which is interconnected at a first end 31 to a substrate and at a second end 32 to a load. The arm 30 is conductively heated so as to expand and exert a force on the load 32. Upon conductive heating, the temperature profile will be approximately as illustrated in Fig. 12. The two ends 31, 32 act as "heat sinks" for the conductive thermal heating and so the temperature profile is cooler at each end and hottest in the middle. The operational characteristics of the arm 30 will be determined by the melting point 35 in that if the temperature in the middle 36 exceeds the melting point 35, the arm may fail. The graph of Fig. 12 represents a non optimal result in that the arm 30 in Fig. 11 is not heated uniformly along its length.

By modifying the arm 30, as illustrated in Fig. 13, through the inclusion of heat sinks 38, 39 in a central portion of the arm 30 a more optimal thermal profile, as illustrated in Fig. 14, can be achieved. The profile of Fig. 14 has a more uniform heating across the lengths of the arm 30 thereby providing for more efficient overall operation.

Turning to Fig. 15, further efficiencies and reduction in buckling likelihood can be achieved by providing a series of struts to couple the two actuator activation arms 24, 25. Such an arrangement is illustrated schematically in Fig. 15 where a series of struts, eg. 40, 41 are provided to couple the two arms 24, 25 so as to prevent buckling thereof. Hence, when the bottom arm 25 is heated, it is more likely to bend upwards causing the actuator arm 23 also to bend upwards.

One form of detailed construction of a ink jet printing MEMS device will now be described. In some of the Figures, a 1 micron grid, as illustrated in Fig. 17 is utilized as a frame of reference.

1 & 2. The starting material is assumed to be a CMOS wafer 100, suitably processed and passivated (using say silicon nitride) as illustrated in Fig. 16 to Fig. 18.

3. As shown in Fig. 19 to Fig. 21, 1 micron of spin-on photosensitive polyimide 102 is deposited and exposed using UV light through the Mask 104 of Fig. 20. The polyimide 102 is then developed.

The polyimide 102 is sacrificial, so there is a wide range of alternative materials which can be used. Photosensitive polyimide simplifies the processing, as it eliminates deposition, etching, and resist stripping steps.

4. As shown in Fig. 22 to Fig. 24, 0.2 microns of magnetron sputtered titanium nitride 106 is deposited at 300 °C and etched using the Mask 108 of Fig. 23. This forms a layer containing the actuator layer 105 and paddle 107.

5. As shown in Fig. 25 to Fig. 27, 1.5 microns of photosensitive polyimide 110 is spun on and exposed using UV light through the Mask 112 of Fig. 26. The polyimide 110 is then developed. The thickness ultimately determines the gap 101 between the actuator and compensator Tin layers, so has an effect on the amount that the actuator bends.

As with step 3, the use of photosensitive polyimide simplifies the processing, as it eliminates deposition, etching, and resist stripping steps.

6. As shown in Fig. 28 to Fig. 30, deposit 0.05 microns of conformal PECVD silicon nitride ($Si_xN_yH_z$) (not shown because of relative dimensions of the various layers) at 300 °C. Then 0.2 microns of magnetron sputtered titanium nitride 116 is deposited, also at 300 °C. This TiN 116 is etched using the Mask 119 of Fig. 29. This TiN 116 is then used as a mask to etch the PECVD nitride.

Good step coverage of the TiN 116 is not important. The top layer of TiN 116 is not electrically connected, and is used purely as a mechanical component.

7. As shown in Fig. 31 to Fig. 33, 6 microns of photosensitive polyimide 118 is spun on and exposed using UV light through the Mask 120 of Fig. 32. The polyimide 118 is then developed. This thickness determines the height to the nozzle chamber roof. As long as this height is above a certain distance (determined by drop break-off characteristics), then the actual height is of little significance. However, the height should be limited to reduce stress and increase lithographic accuracy. A taper of 1 micron can readily be accommodated between the top and the bottom of the 6 microns of polyimide 118.

8. As shown in Fig. 34 to Fig. 36, 2 microns (thickness above polyimide 118) of PECVD silicon nitride 122 is deposited at 300°C. This fills the channels formed in the previous PS polyimide layer 118, forming the nozzle chamber. No mask is used (Fig. 35).

9. As shown in Fig. 37 to Fig. 39, the PECVD silicon nitride 122 is etched using the mask 124 of Fig. 38 to a nominal depth of 1 micron. This is a simple timed etch as the etch depth is not critical, and may vary up to ± 50%.

The etch forms the nozzle rim 126 and actuator port rim 128. These rims are used to pin the meniscus of the ink to certain locations, and prevent the ink from spreading.

10. As shown in Fig. 40 to Fig. 42, the PECVD silicon nitride 122 is etched using the mask 130 of Fig. 41 to a nominal depth of 1 micron, stopping on polyimide 118. A 100% over-etch can accommodate variations in the previous two steps, allowing loose manufacturing tolerances.

The etch forms the roof 132 of the nozzle chamber.

11. As shown in Fig. 43 to Fig. 45, nominally 3 microns of polyimide 134 is spun on as a protective layer for back-etching (No Mask - Fig. 44).

12. As shown in Fig. 46 to Fig. 48, the wafer 100 is thinned to 300 microns (to reduce back-etch time), and 3 microns of resist (not shown) on the back-side 136 of the wafer 100 is exposed through the mask 138 of Fig. 47. Alignment is to metal portions 103 on the front side of the wafer 100. This alignment can be achieved using an IR microscope attachment to the wafer aligner.

The wafer 100 is then etched (from the back-side 136) to a depth of 330 microns (allowing 10% over-etch) using the deep silicon etch "Bosch process". This process is available on plasma etchers from Alcatel, Plasma-therm, and Surface Technology Systems. The chips are also diced by this etch, but the wafer is still held together by 11 microns of the various polyimide layers.

13. As illustrated with reference to Fig. 49 to Fig. 51, the wafer 100 is turned over, placed in a tray, and all of the sacrificial polyimide layers 102, 110, 118 and 134 are etched in an oxygen plasma using no mask (Fig. 60).

14. As illustrated with reference to Fig. 52 to Fig. 54, a package is prepared by drilling a 0.5mm hold in a standard package, and gluing an ink hose (not shown) to the package. The ink hose should include a 0.5 micron absolute filter to prevent contamination of the nozzles from the ink 121.

Figures 55 to 62 illustrate various views of the preferred embodiment, some illustrating the embodiments in operation.

Obviously, large arrays 200 of print heads 202 can be simultaneously constructed as illustrated in Fig. 63 to Fig. 56 which illustrate various print head array views.

The presently disclosed ink jet printing technology is potentially suited to a wide range of printing systems including: colour and monochrome office printers, short run digital printers, high speed digital printers, offset press supplemental printers, low cost scanning printers, high speed pagewidth printers, notebook computers with in-built pagewidth printers, portable colour and monochrome printers, colour and monochrome copiers, colour and monochrome facsimile machines, combined printer, facsimile and copying machines, label printers, large format plotters, photograph copiers, printers for digital photographic 'minilabs', video printers, PhotoCD printers, portable printers for PDAs, wallpaper printers, indoor sign printers, billboard printers, fabric printers, camera printers and fault tolerant commercial printer arrays.

Further, the MEMS principles outlined have general applicability in the construction of MEMS devices.

It would be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the preferred embodiment without departing from the spirit or scope of the invention as broadly

described. The preferred embodiment is, therefore, to be considered in all respects to be illustrative and not restrictive.

We Claim

1. A thermal actuator for micro electro-mechanical devices, the actuator comprising:

a supporting substrate,

an actuator actuation portion,

a first arm attached at a first end thereof to the substrate and at a second end to the actuation portion, the first arm being arranged, in use, to be conductively heatable,

a second arm attached at a first end to the supporting substrate and at a second end to the actuation portion, the second arm being spaced apart from the first arm, whereby the first and second arm define a gap between them; and

wherein, in use, the first arm is arranged to undergo thermal expansion when conductively heated, thereby causing a force to be applied to the actuation portion.

2. A thermal actuator as claimed in claim 1, wherein the actuator is arranged in a manner such that a heating current can be applied to the first arm through the supporting substrate.

3. A thermal actuator as claimed in claims 1 or 2, wherein the first and second arm are formed from substantially the same material.

4. A thermal actuator as claimed in any one of the preceding claims, wherein the actuator is manufactured by the steps of: depositing and etching a first layer to form the first arm; depositing and etching a second layer to form a sacrificial layer supporting structure over the first arm; and depositing and etching a third layer to form the second arm, and etching the second layer to form the gap between the first and second arms.

5. A thermal actuator as claimed in any one of the preceding claims, wherein the first arm comprises at least two elongated flexible strips conductively interconnected at the second end.

6. A thermal actuator as claimed in any one of the preceding claims, wherein the second arm comprises at least two elongated flexible strips.

7. A thermal actuator as claimed in any one of the preceding claims, wherein the actuation portion comprises a paddle structure.

8. A thermal actuator as claimed in any one of the preceding claims, wherein the first arm is formed from titanium nitride.

9. A paddle for ejecting liquid from within a nozzle chamber out through a liquid ejection nozzle defined in one wall of the nozzle chamber, the paddle comprising:

a first portion being configured to, in use, provide a substantially planar plunger surface opposite to and spaced apart from the nozzle, and

a second portion formed on the plunger surface in the periphery of the first portion for providing structural support for the first portion,

whereby, in use, during actuation of the plunger to eject liquid through the nozzle the second portion acts as a spacer preventing the plunger surface from reaching the nozzle.

10. A paddle as claimed in claim 9, wherein the second portion may be configured to define a wall structure around a center portion of the plunger surface, the center portion, in use, being substantially aligned with the nozzle.

11. A paddle as claimed in claim 10, wherein the center portion may preferably be of the same dimensions as the nozzle.

12. A paddle as claimed in any one of claims 9 to 11, wherein the first portion can have a circular circumference and the second portion can comprise an annulus around the circumference of the paddle.

13. A paddle as claimed in claim 10, wherein the wall structure is in part undercut.

14. A paddle as claimed in claim 13, wherein the paddle is formed by depositing and etching a first layer to form the first portion; depositing and etching a second layer to form a sacrificial layer structure on part of the first portion; and depositing and etching a third layer to form the second portion, and etching the sacrificial layer so that the second portion ins in part undercut.

15. A mechanical actuator for micro mechanical or micro electro-mechanical devices, the actuator comprising:

a supporting substrate,

an actuation portion,

a first arm attached at a first end thereof to the substrate and at a second end to the actuation portion, the first arm being arranged, in use, to be conductively heatable,

a second arm attached at a first end to the supporting substrate and at a second end to the actuation portion, the second arm being spaced apart from the first arm, whereby the first and second arm define a gap between them,

at least one rigid member interconnecting the first and second arms between the first and second ends thereof, and

wherein, in use, the first arm is arranged to undergo expansion, thereby causing the actuator to apply a force to the actuation portion.

16. An actuator as claimed in claim 15, wherein the first arm preferably comprises:

a first main body formed between the first and second ends of the first arm;

at least one tab body connected to the first main body; and

wherein a first one of the at least one rigid members interconnecting the tab with the second arm.

17. An actuator as claimed in claim 16, wherein the second arm comprises:

a second main body formed between the first and second end of the second arm;

at least one corresponding tab body connected to the second main body; and

wherein the first one of the at least one rigid members interconnecting the corresponding tabs of the first and second arms.

18. An actuator as claimed in claims 16 or 17, wherein the tab body is connected to the first main body via a first thinned neck portion.

19. An actuator as claimed in claims 17 or 18, wherein the corresponding tab body is connected to the second main body via a second thinned neck portion.

20. An actuator as claimed in any one of claims 15 to 19, wherein the first arm comprises a conductive layer whereby the first arm is conductively heatable to cause, in use, the first arm to undergo thermal expansion relative to the second arm thereby causing the actuator to apply a force to the actuation portion.

21. An actuator as claimed in any one of claims 15 to 20, wherein the first and second arms are substantially parallel and the rigid member is substantially perpendicular to the first and second arms.

22. An actuator as claimed in any one of claims 15 to 21, wherein the actuator is arranged in a manner such that a current can be supplied, in use, to the conductive layer through the supporting substrate.

23. An actuator as claimed in any one of claims 15 to 22, wherein the first and second arm are formed from substantially the same material.

24. An actuator as claimed in any one of claims 15 to 23, wherein actuator is manufactured by the steps of:

depositing and etching a first layer to form the first arm;

depositing and etching a second layer to form a sacrificial layer supporting structure over the first arm;

depositing and etching a third layer to form the second arm, and

etching the sacrificial layer to form the gap between the first and second arms.

25. An actuator as claimed in any one of claims 15 to 24, wherein the first arm comprises two first elongated flexible strips conductively interconnected at the second end.

26. An actuator as claimed in any one of claims 15 to 25, wherein the second arm comprises two second elongated flexible strips.

27. An actuator as claimed in any one of claims 15 to 26, wherein the actuation portion comprises a paddle structure.

28. An actuator as claimed in any one claims 15 to 27, wherein the first arm is formed from titanium nitride.

29. An actuator as claimed in any one of claims 15 to 28, wherein the second arm is formed from titanium nitride.

30. A thermal actuator for micro mechanical or micro electro-mechanical devices, the actuator comprising:

a supporting substrate,

an actuator extension portion,

a first arm attached at a first end thereof to the substrate and at a second end to the extension portion, the first arm being arranged, in use, to be conductively heatable,

a second arm attached at a first end to the supporting substrate and at a second end to the extension portion, the second arm being spaced apart from the first arm,

the first arm being arranged , in use, to undergo thermal expansion, thereby causing the actuator to apply a force to the extension portion, and

wherein the first arm comprises at least one heat sink element substantially at a point of maximum heating of the first arm, being the point where, in use, maximum heating of the first arm would occur.

31. An actuator as claimed in claim 30, wherein the heat sink element is located substantially in the middle of the first arm.

32. An actuator as claimed in claims 30 or 31, wherein the heat sink element is arranged to interconnect the first and second arm.

33. An actuator as claimed in any one of claims 30 to 32, wherein the heat sink element comprises at least one tab body connected to a main body of the first arm.

34. An actuator as claimed in claim 33, wherein the tab body is connected to the main body via a first thinned neck portion.

35. An actuator as claimed in any one of claims 30 to 34, wherein the first arm comprises a conductive layer whereby the first arm is conductively heatable.

36. An actuator as claimed in claim 35, wherein The actuator is arranged in a manner such that a current can be supplied to the conductive layer through the supporting substrate.

37. An actuator as claimed in any one of claims 30 to 36, wherein the first and second arms are preferably formed from substantially the same material.

38. An actuator as claimed in any one of claims 30 to 37, wherein the extension portion comprises a paddle structure.

39. An actuator as claimed in any one of claims 30 to 38, wherein the first arm is formed from titanium nitride.

40. An actuator as claimed in any one of claims 30 to 39, wherein the second arm is formed from titanium nitride.

41. A liquid ejection device comprising:

a nozzle chamber having a first aperture in one wall thereof for the ejection of the liquid and a second aperture in a wall thereof through which an actuator arm extends, the actuator arm being attached to a substrate located outside the nozzle chamber and being connected to a paddle inside the nozzle chamber, the paddle being operable by way of the actuator arm to eject the liquid through the first aperture;

a first raised rim formed around the second aperture, the first raised rim being arranged in a manner such that, during operation of the actuator arm, a liquid meniscus is being formed along an outer surface of the liquid between the first raised rim and the actuator arm.

42. A device as claimed in claim 41, wherein the actuator comprises a planar portion adjacent the first raised rim, the planar portion being generally parallel to and spaced apart from the substrate.

43. A device as claimed in claim 42, wherein the first raised rim comprises an edge portion substantially parallel to the planar portion.

44. A device as claimed in any one of claims 41 to 43, wherein the first raised rim comprises a raised lip.

45. A device as claimed in any one of claims 41 to 44, wherein the device further comprises a second raised rim formed on the actuator arm adjacent the first raised rim formed around the second aperture.

46. A device as claimed in any one of claims 41 to 45, wherein the first raised rim is formed from deposition of a layer which also forms a portion of the actuator arm.

47. A device as claimed in any one of claims 41 to 46, wherein at least on of the first and second raised rims is formed from titanium nitride.

48. A device as claimed in any one of claims 41 to 47, wherein adjacent the first raised rim there is preferably formed a pit to assist in reducing wicking.

49. A liquid ejection device comprising:

a nozzle chamber,

an ejection paddle located within the nozzle chamber for ejecting liquid from the nozzle chamber though an aperture in one wall of the nozzle chamber when the paddle is moved from a first state into an ejection state,

a liquid supply port arranged in a manner such that it is substantially closed by the paddle when the paddle is in the first state;

wherein the nozzle chamber comprises an internal protrusion on a wall structure thereof which is aligned closely adjacent to a rim of the paddle when the paddle is in the first state, and

wherein, in the ejection state, at least a portion of the rim of the paddle is spaced apart from the protrusion, thereby forming a liquid refill channel defined between the wall structure and the portion of the rim of the paddle.

50. A device as claimed in claim 49, wherein the internal protrusion may have a staircase-type cross-sectional profile.

51. A device as claimed in any one of claims 49 to 50, wherein the paddle and the internal protrusion are formed in one deposition step.

52. A device as claimed in any one of claims 49 to 51, wherein the internal protrusion is formed using a lower aspect ratio deposition step when compared to a high aspect ratio deposition step for forming the wall structure of the nozzle chamber.

53. A device as claimed in any one of claims 49 to 52, wherein the paddle is substantially planar.

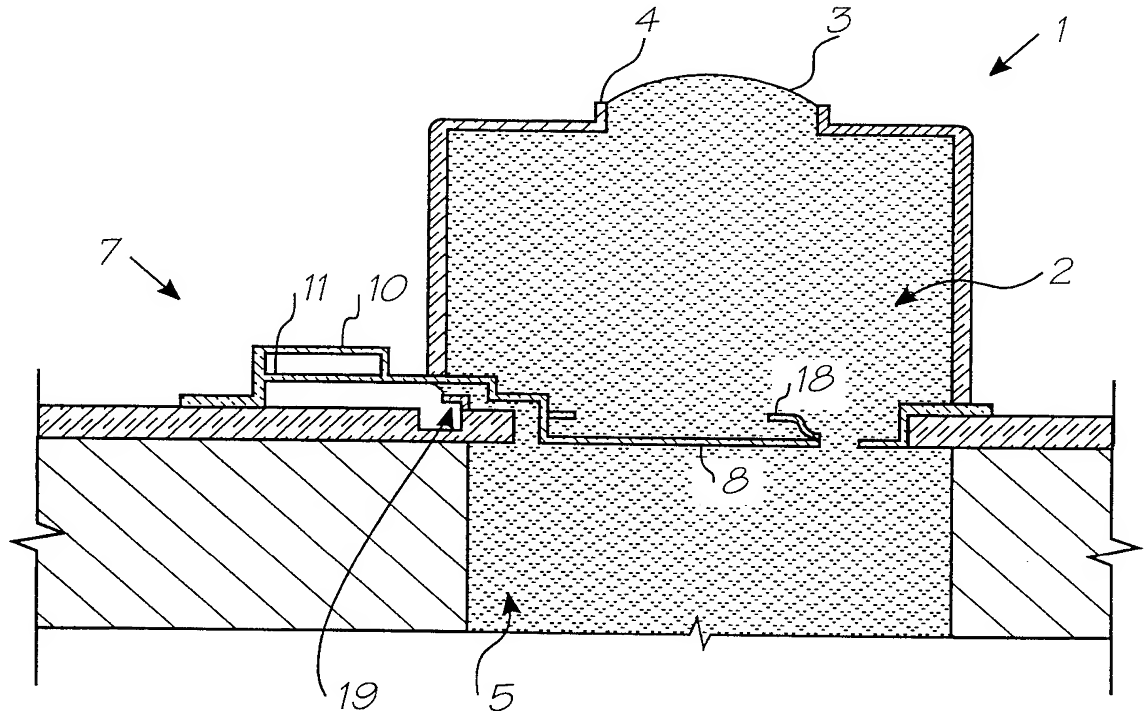


FIG. 1

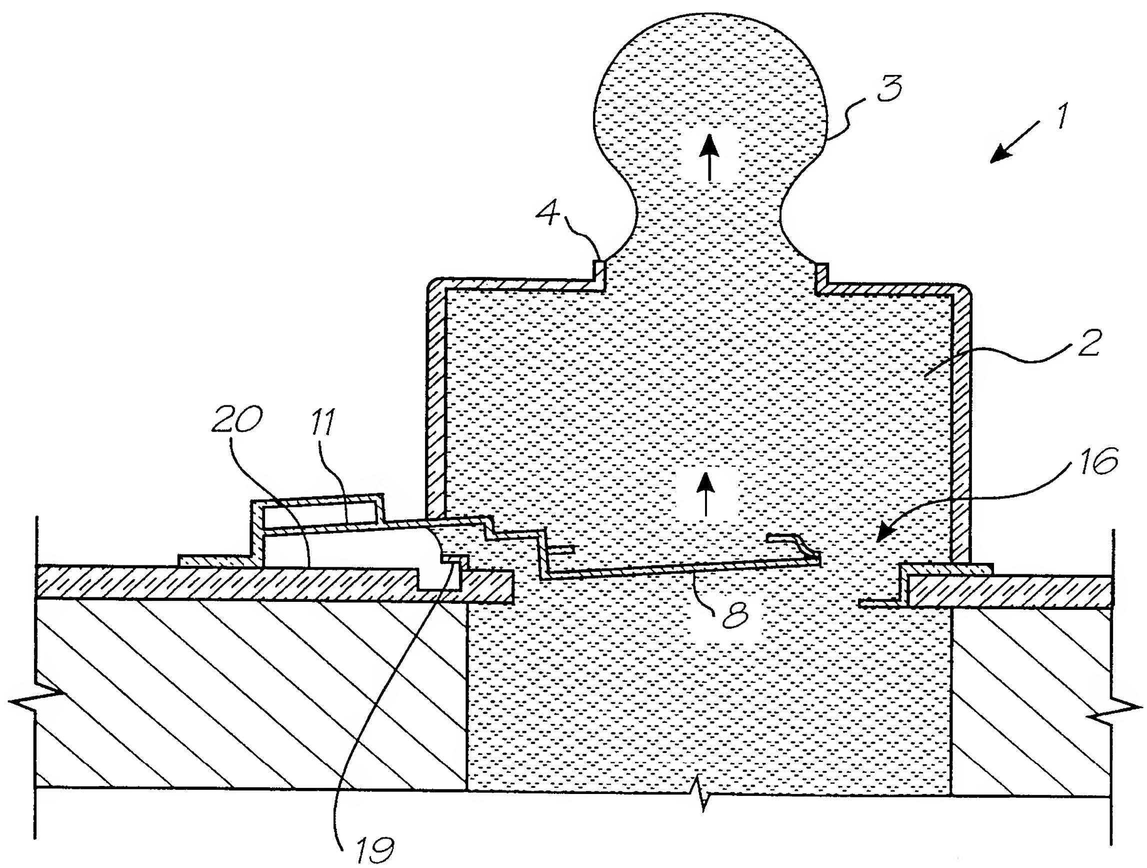


FIG. 2

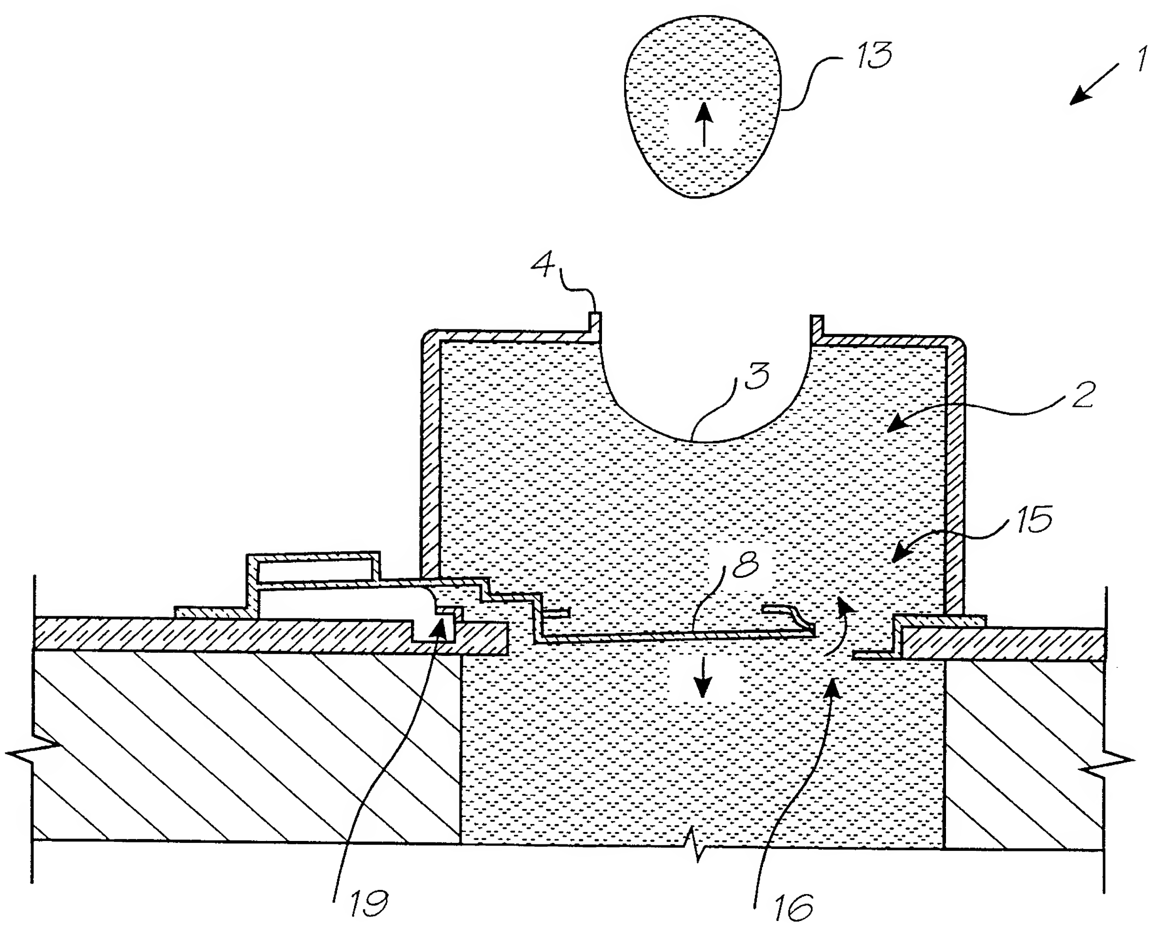


FIG. 3

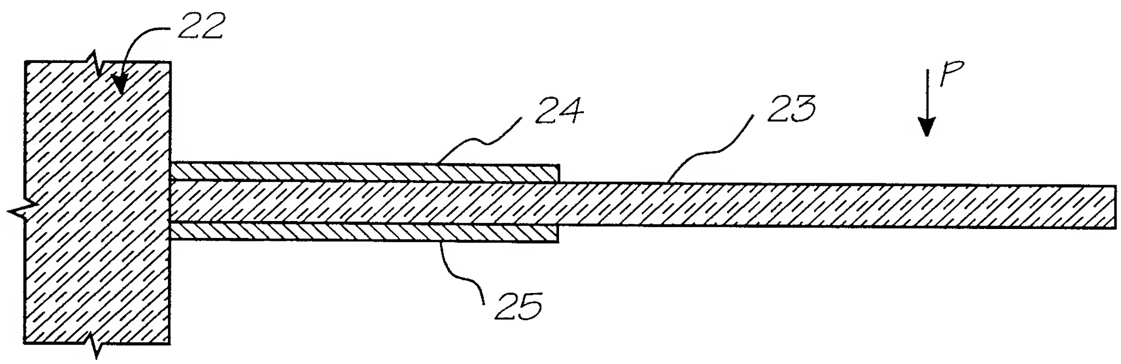


FIG. 4

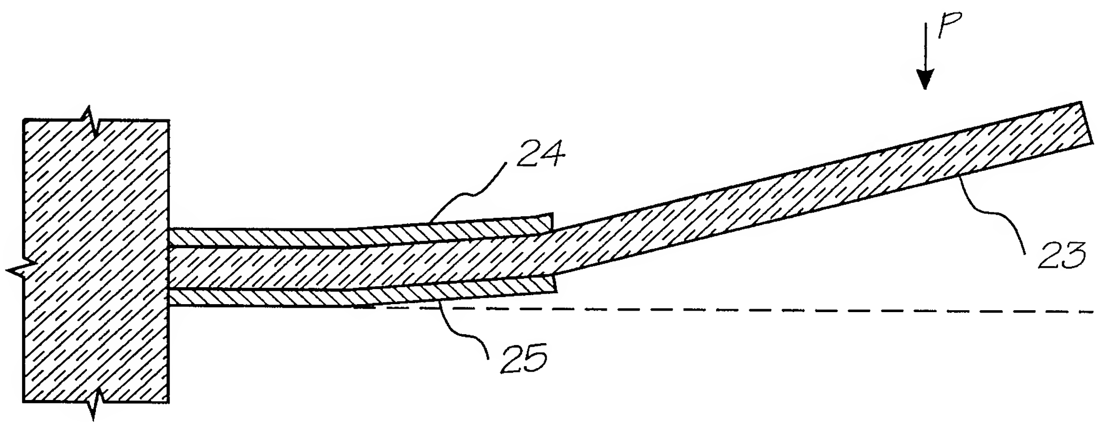


FIG. 5

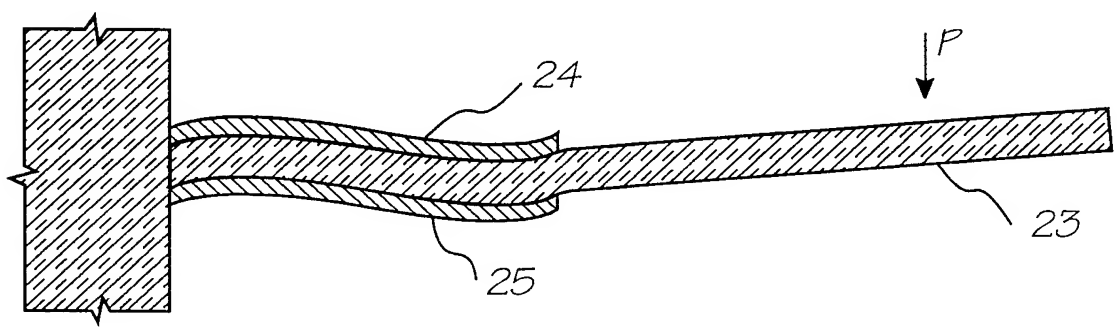


FIG. 6

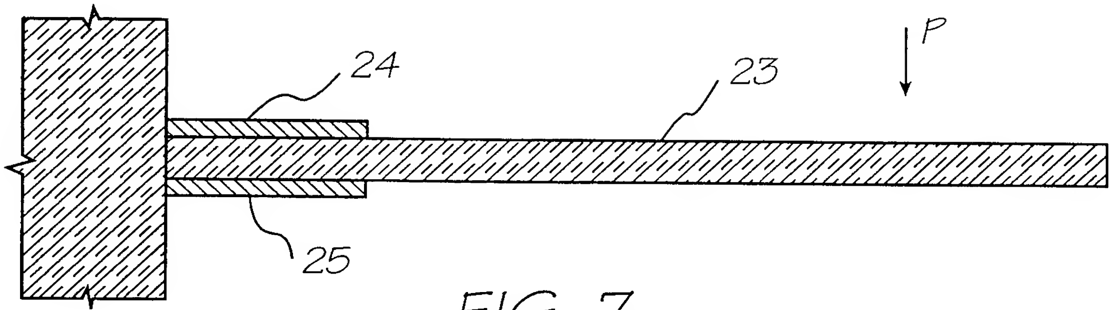


FIG. 7

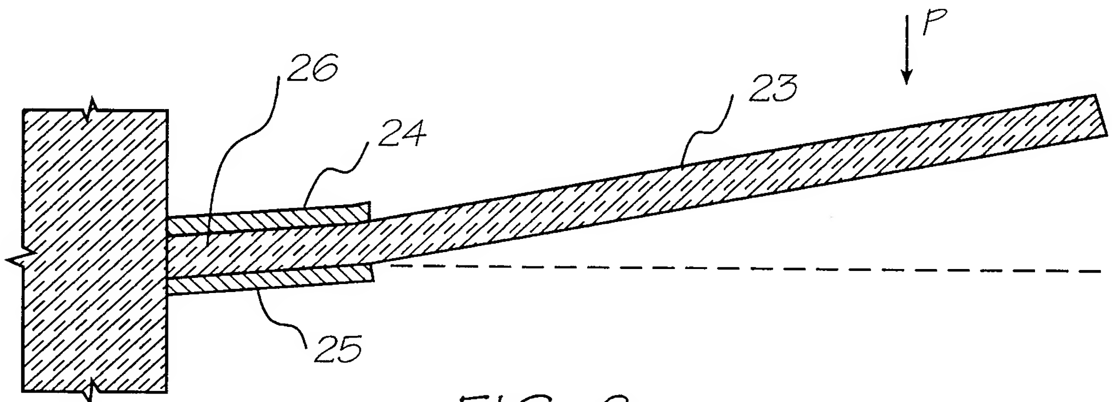


FIG. 8

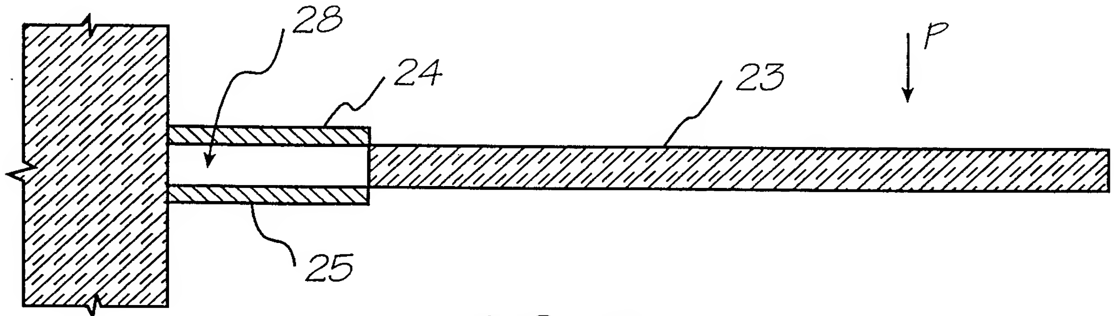


FIG. 9

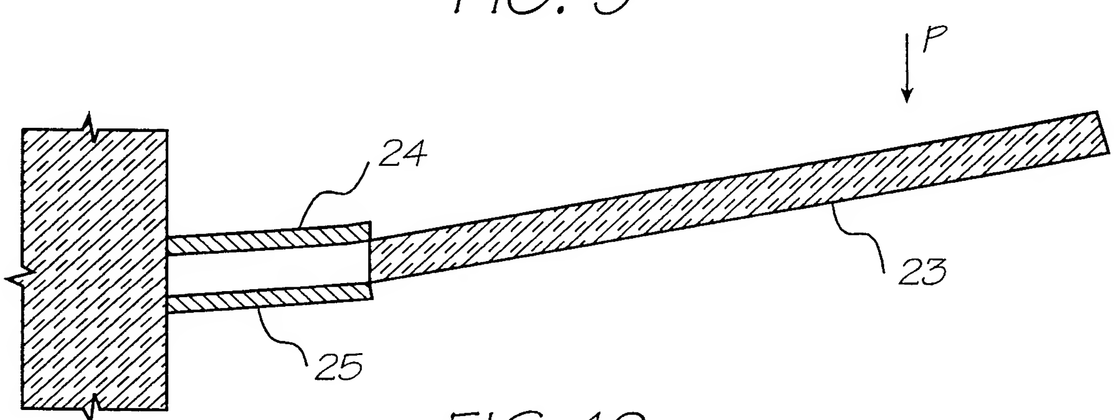


FIG. 10

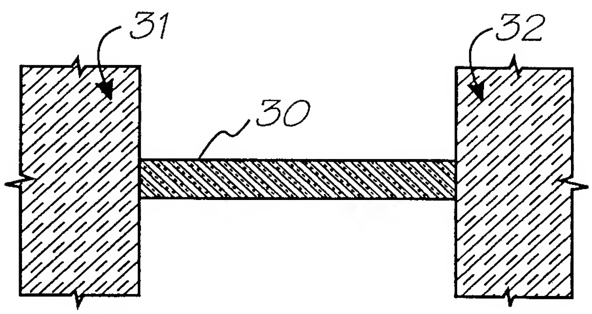


FIG. 11

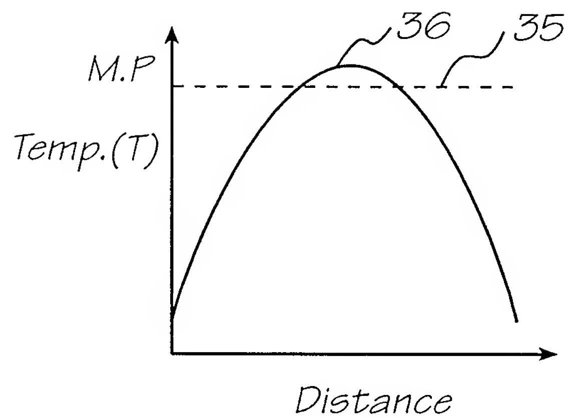


FIG. 12

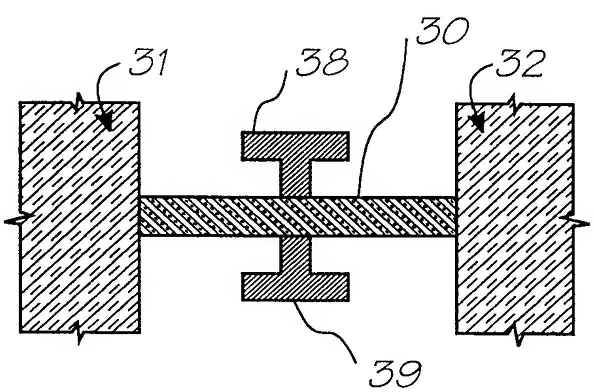


FIG. 13

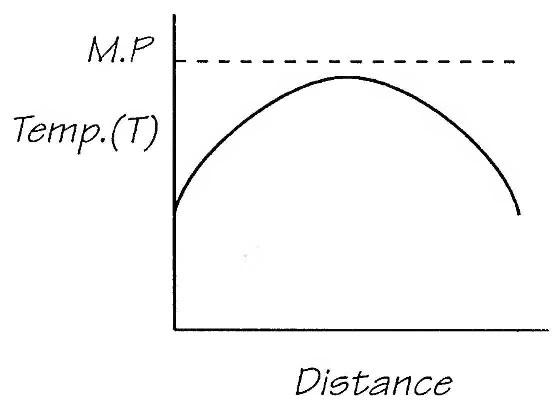


FIG. 14

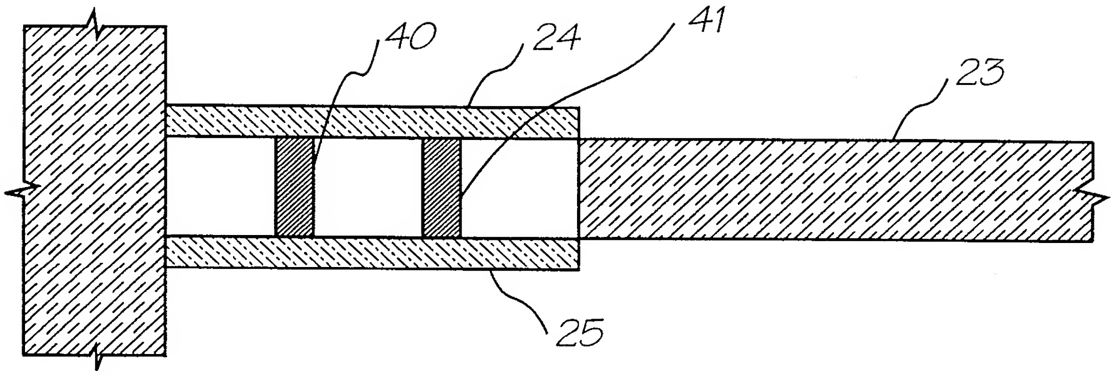


FIG. 15

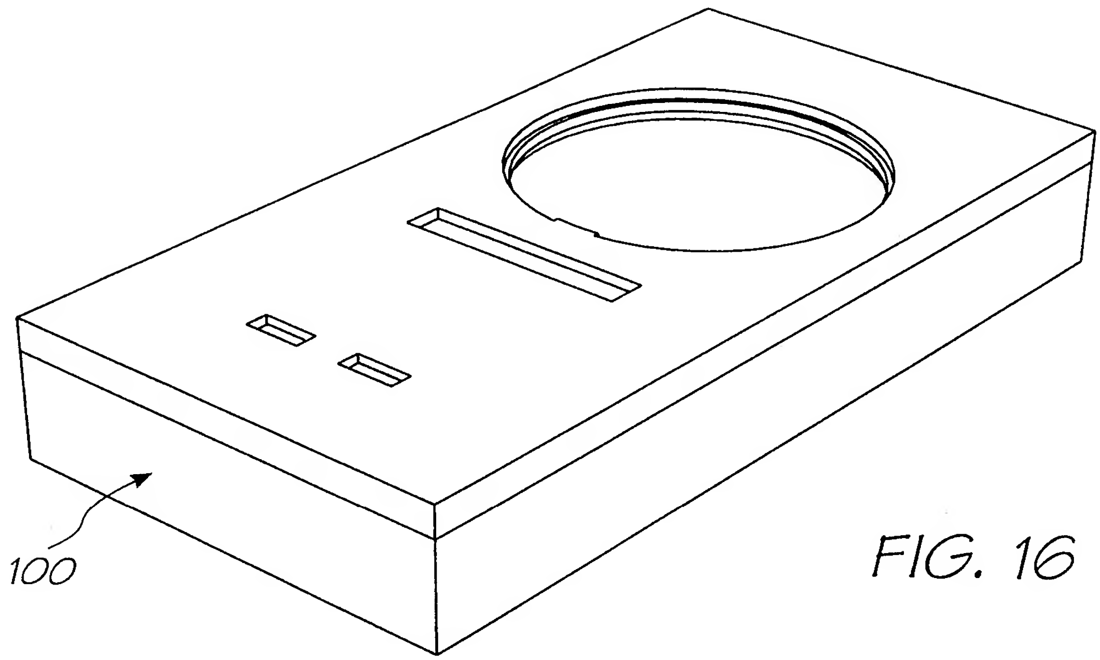
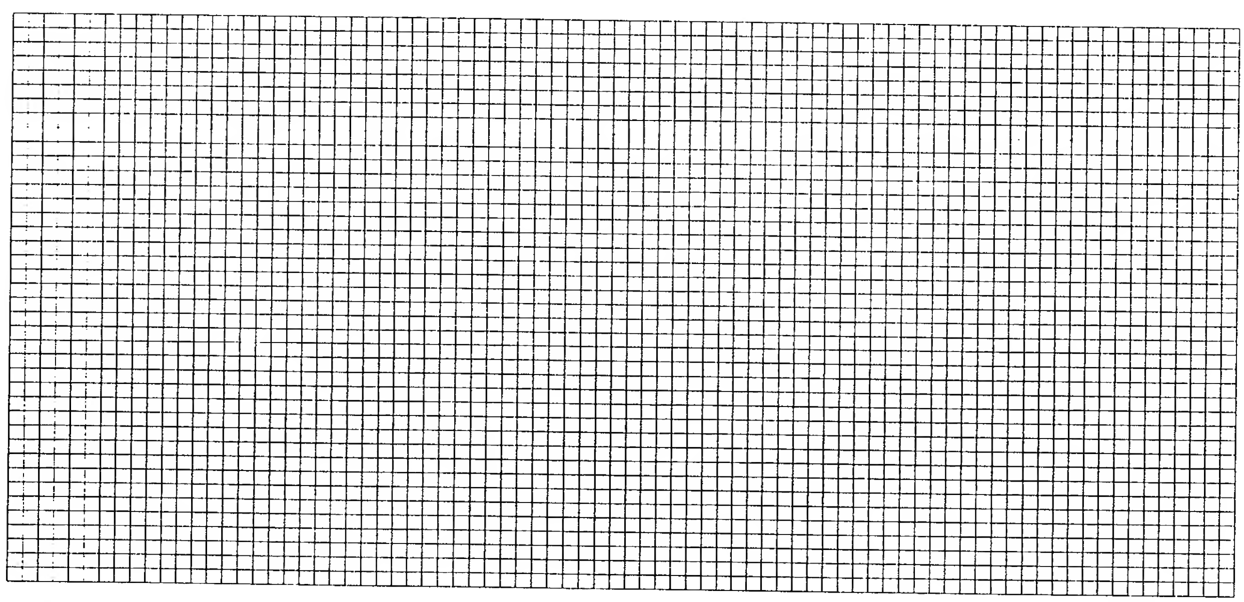
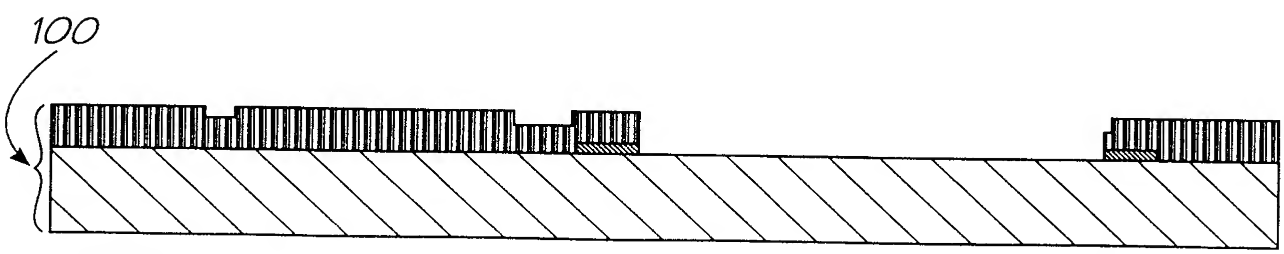


FIG. 16



Mask (Muitiple CMOS masks to this stage)

FIG. 17



CMOS complete

FIG. 18

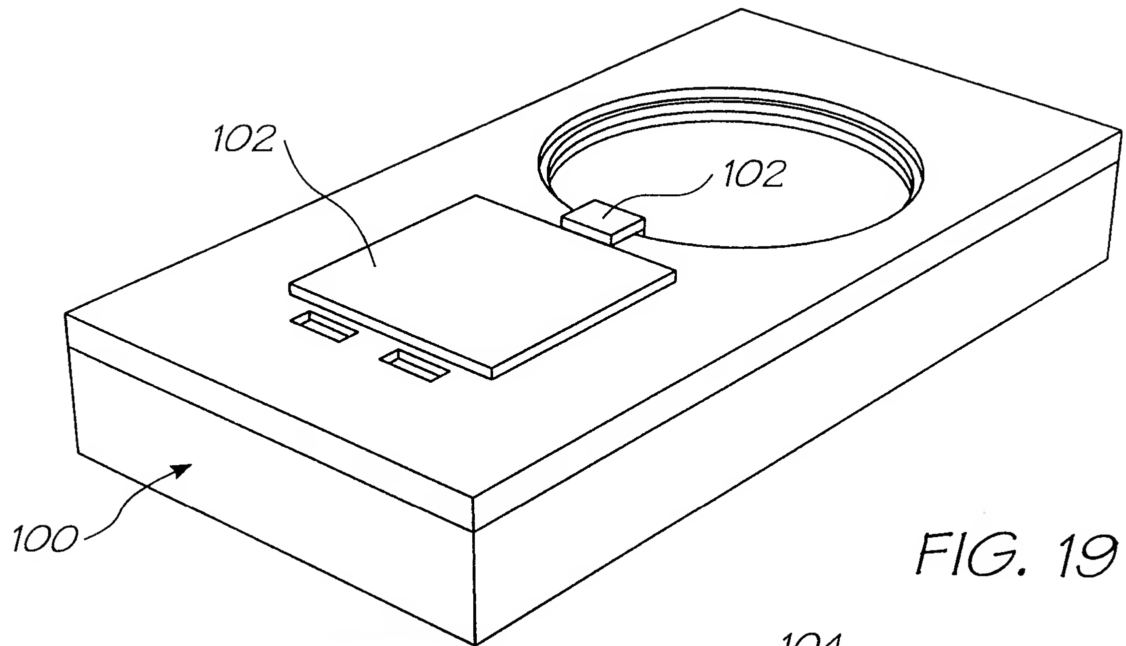
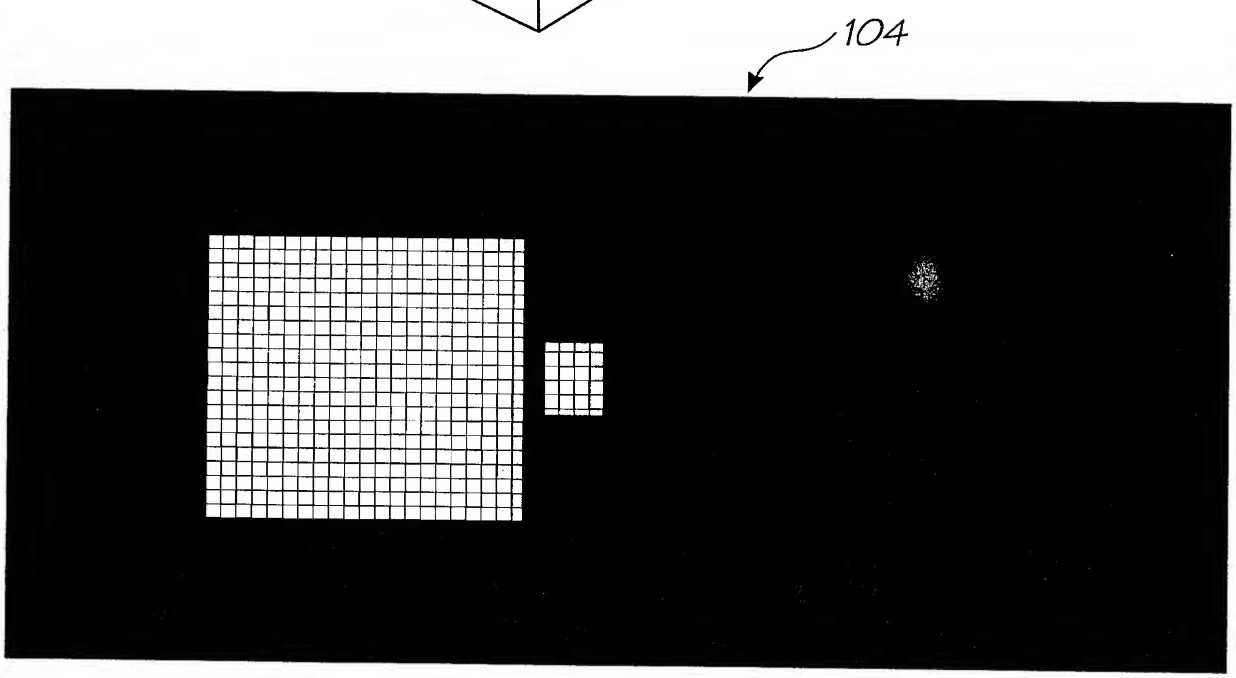
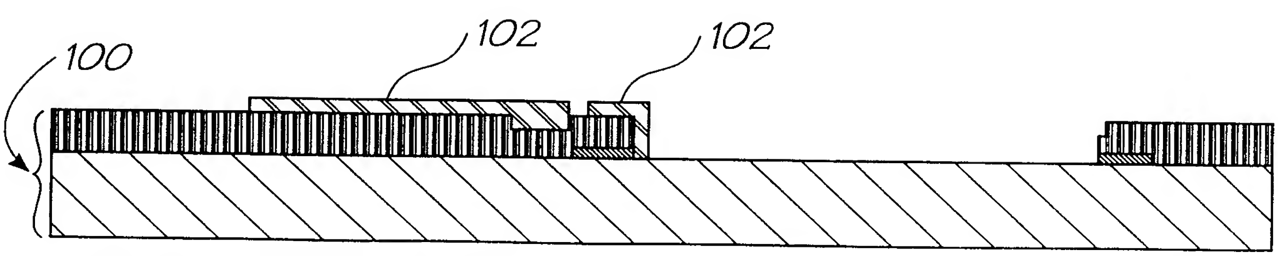


FIG. 19



Mask

FIG. 20



1 micron sacrificial Polyimide

FIG. 21

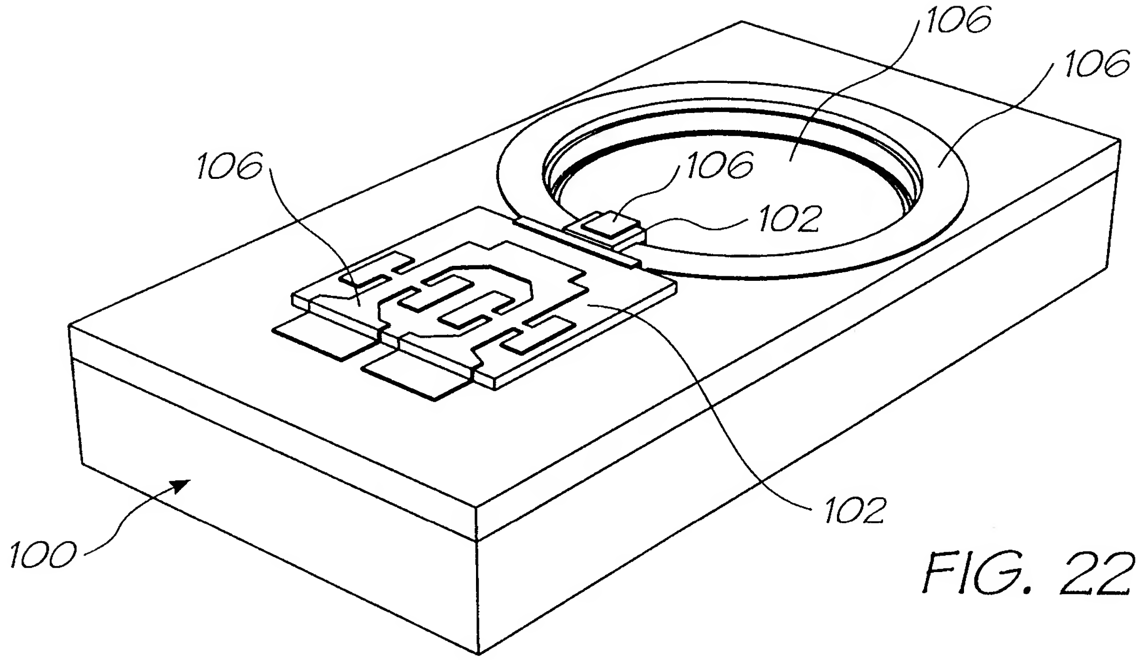
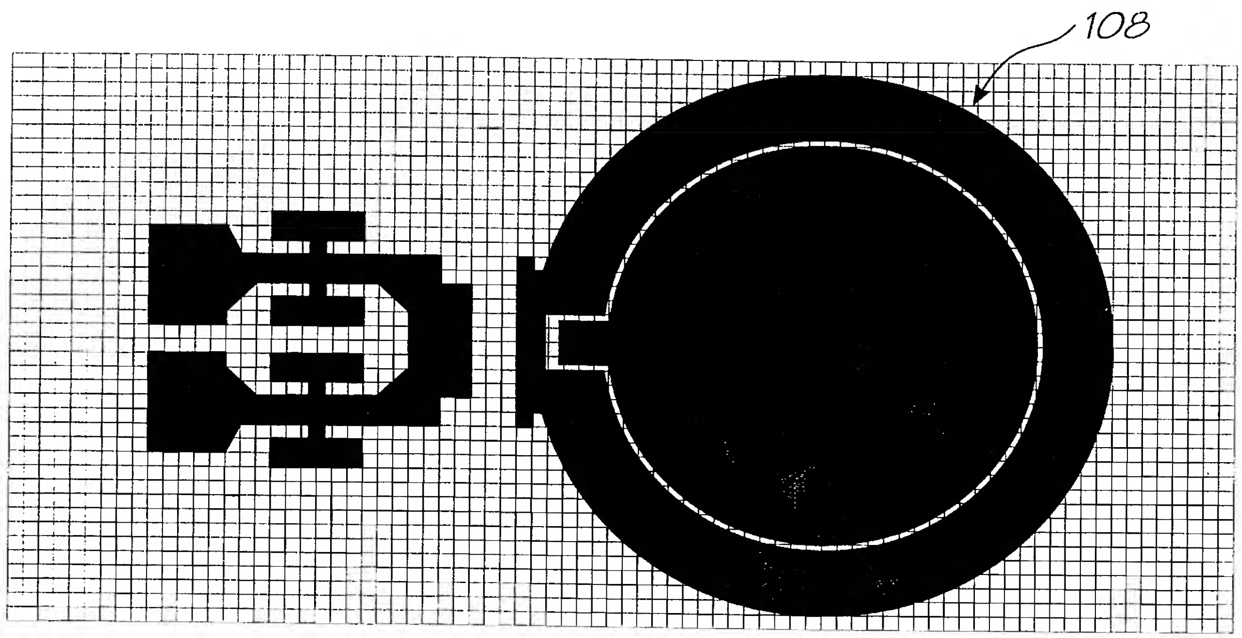
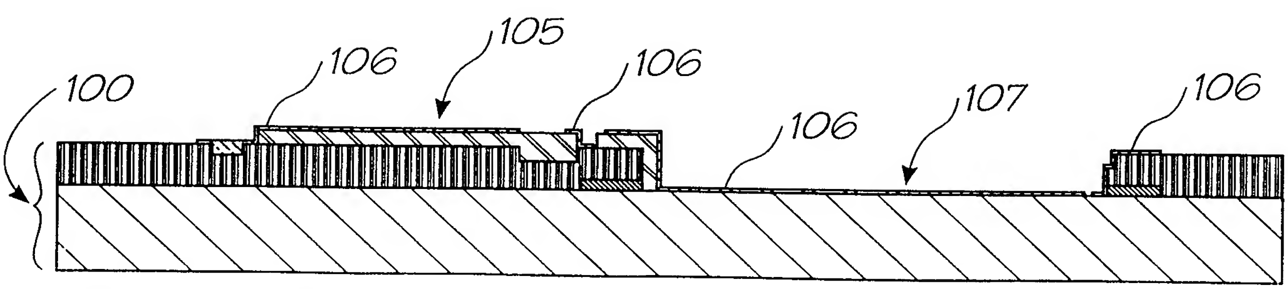


FIG. 22



Mask

FIG. 23



0.2 micron TiN

FIG. 24

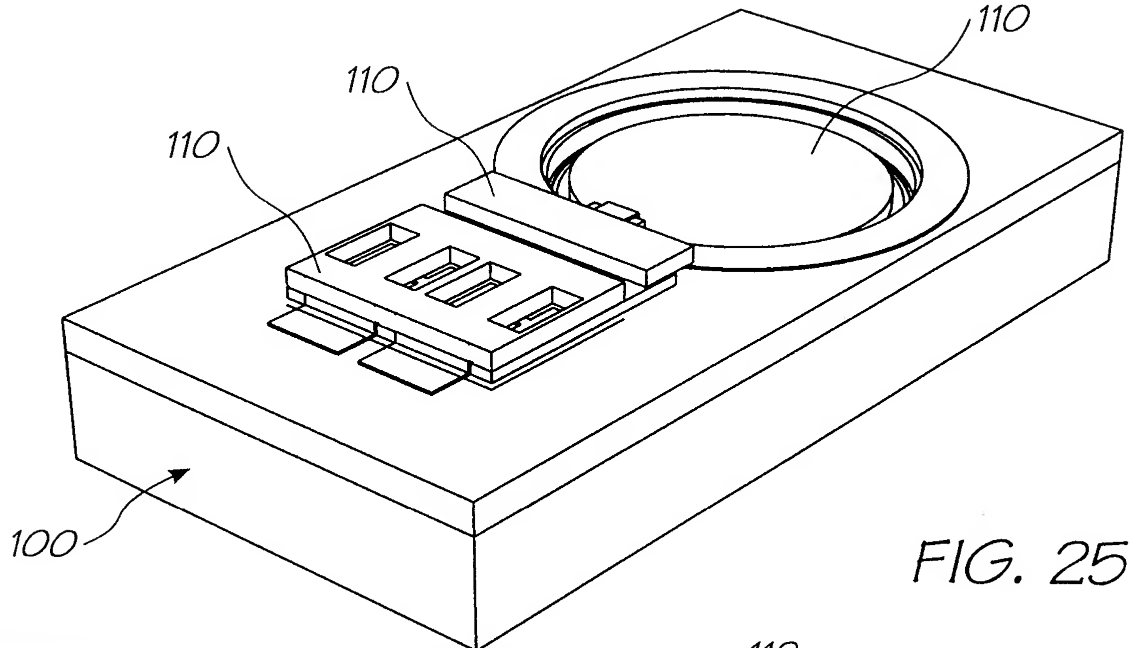
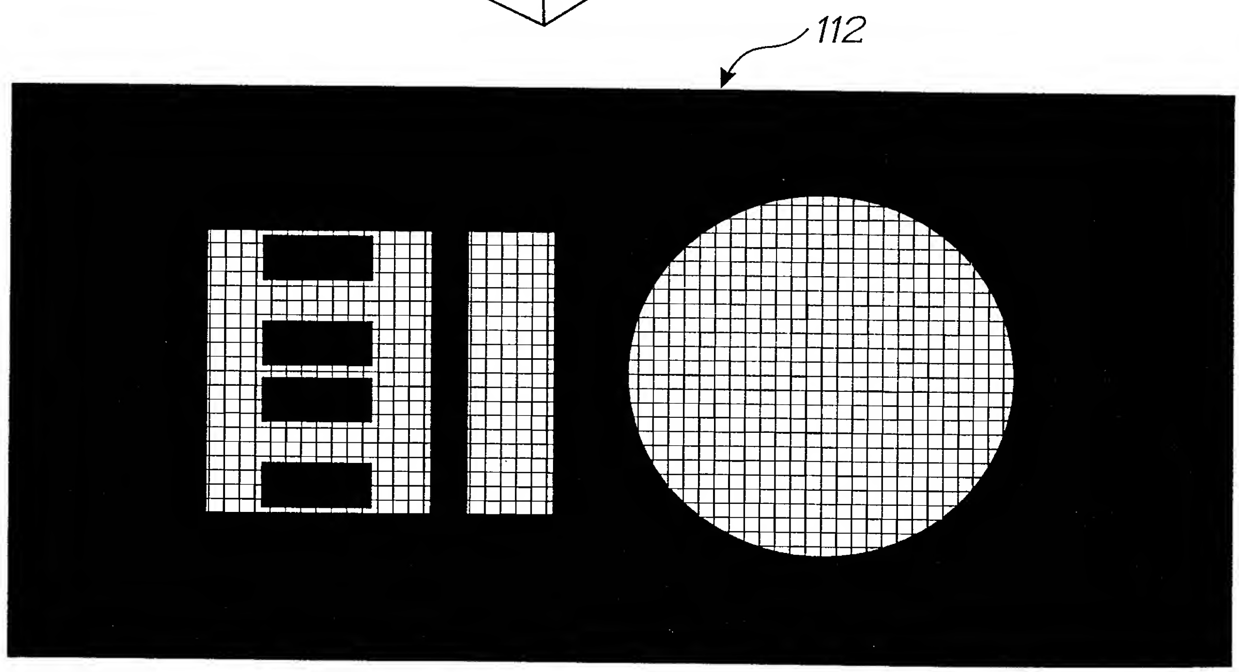
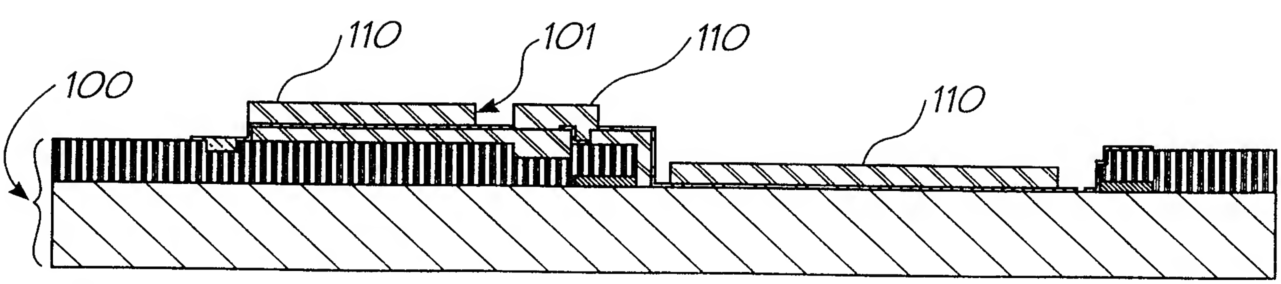


FIG. 25



Mask

FIG. 26



1.5 micron sacrificial Polyimide

FIG. 27

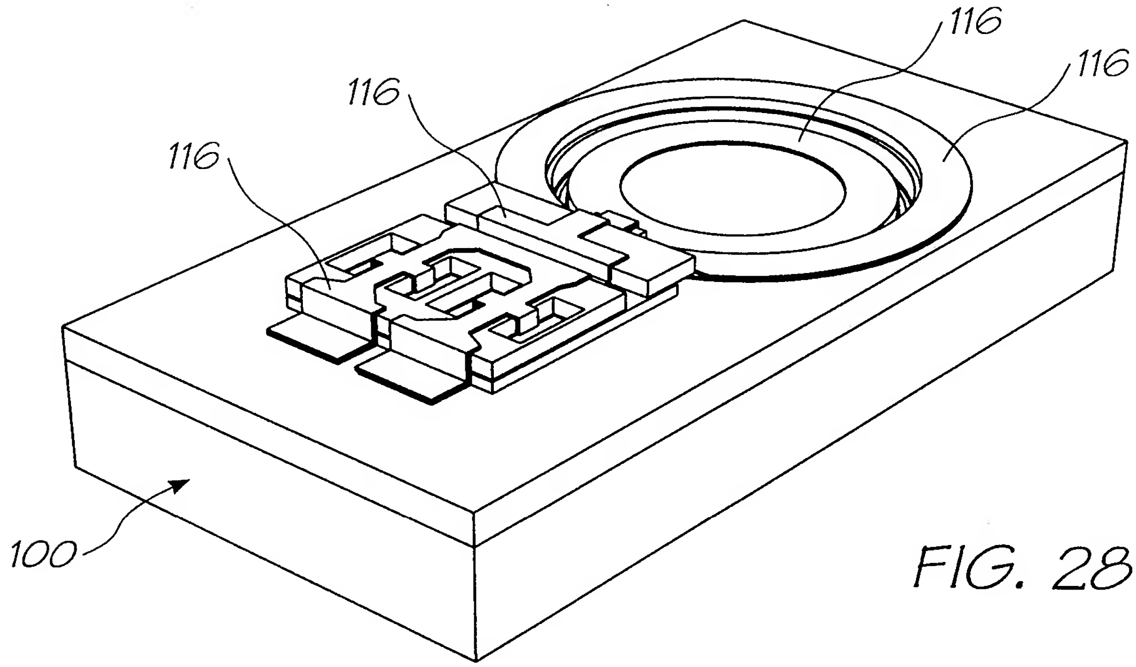
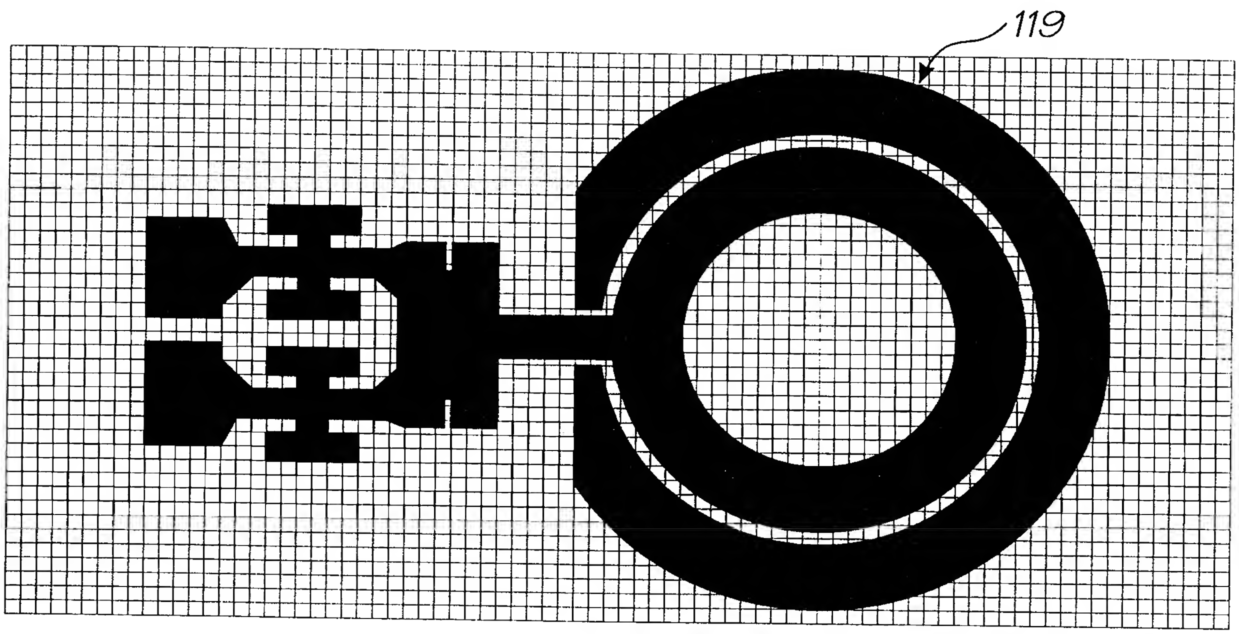
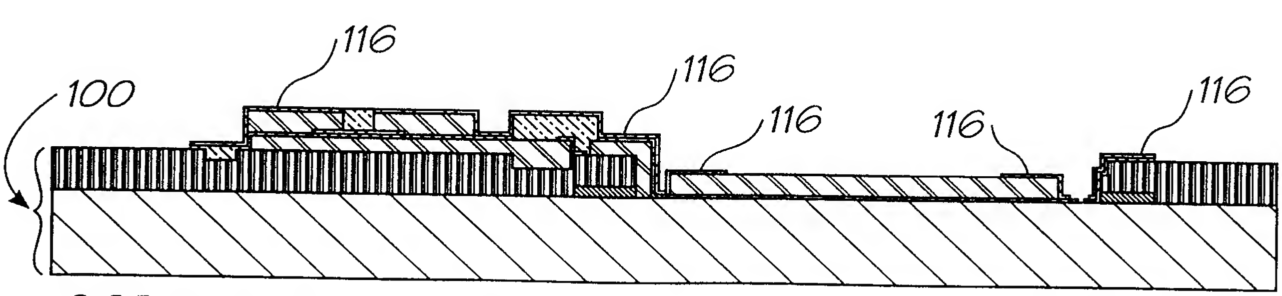


FIG. 28



Mask

FIG. 29



0.05 micron $Si_xN_yH_z$, 0.2 micron TiN

FIG. 30

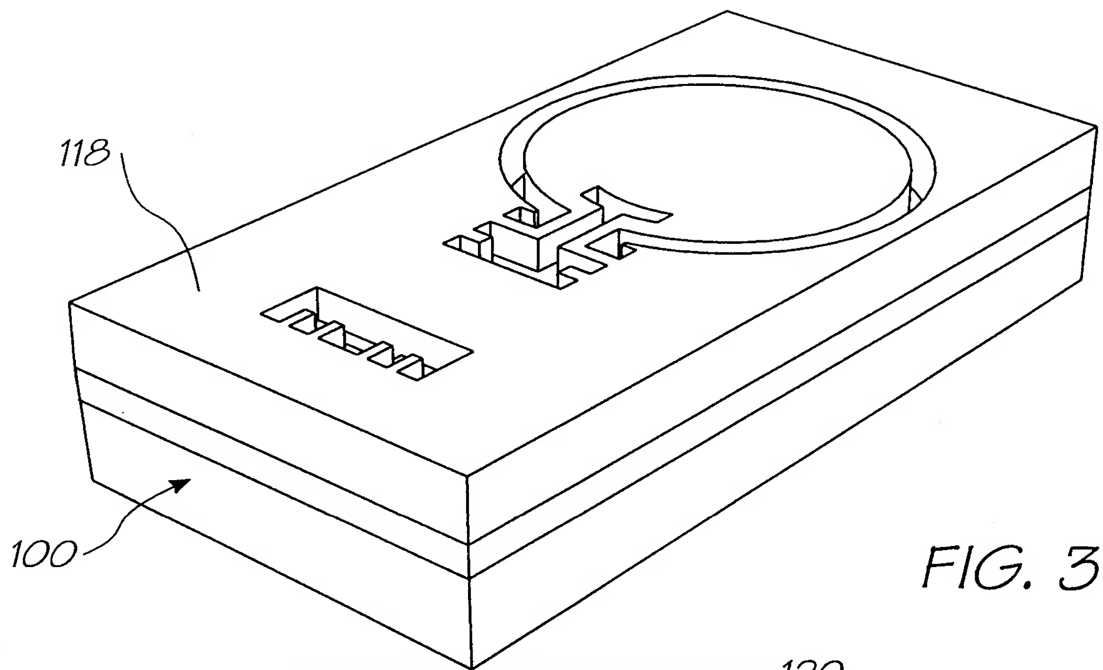
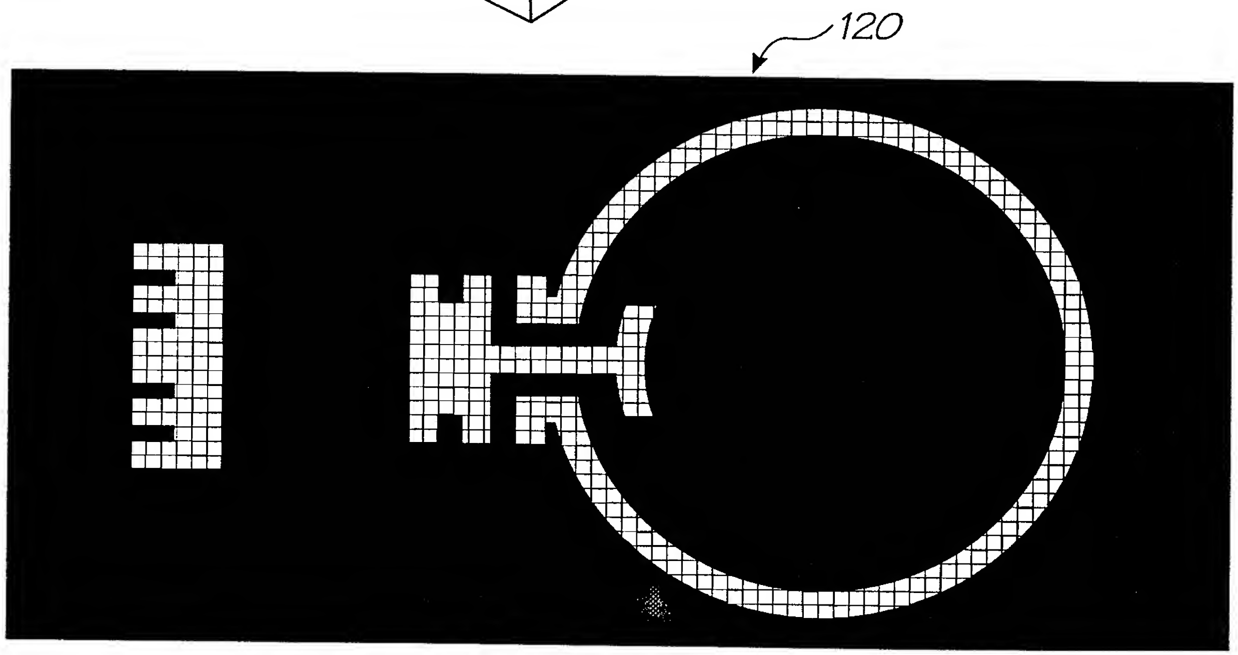
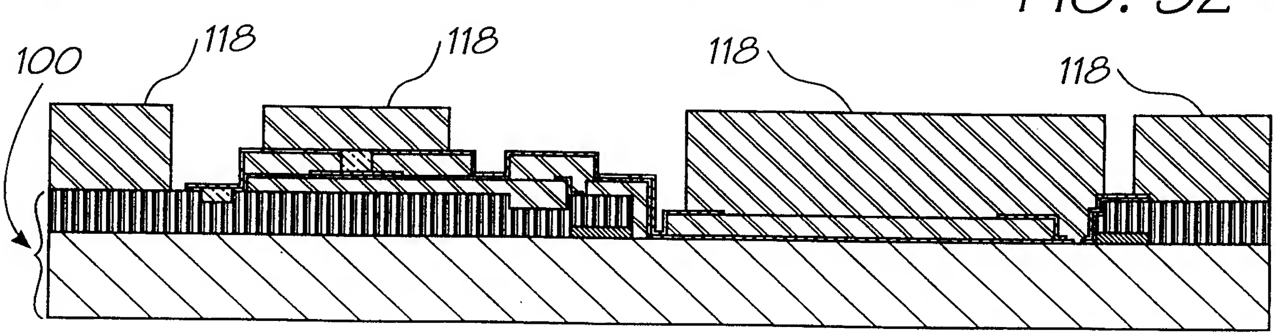


FIG. 31



Mask

FIG. 32



6 microns sacrificial Polyimide

FIG. 33

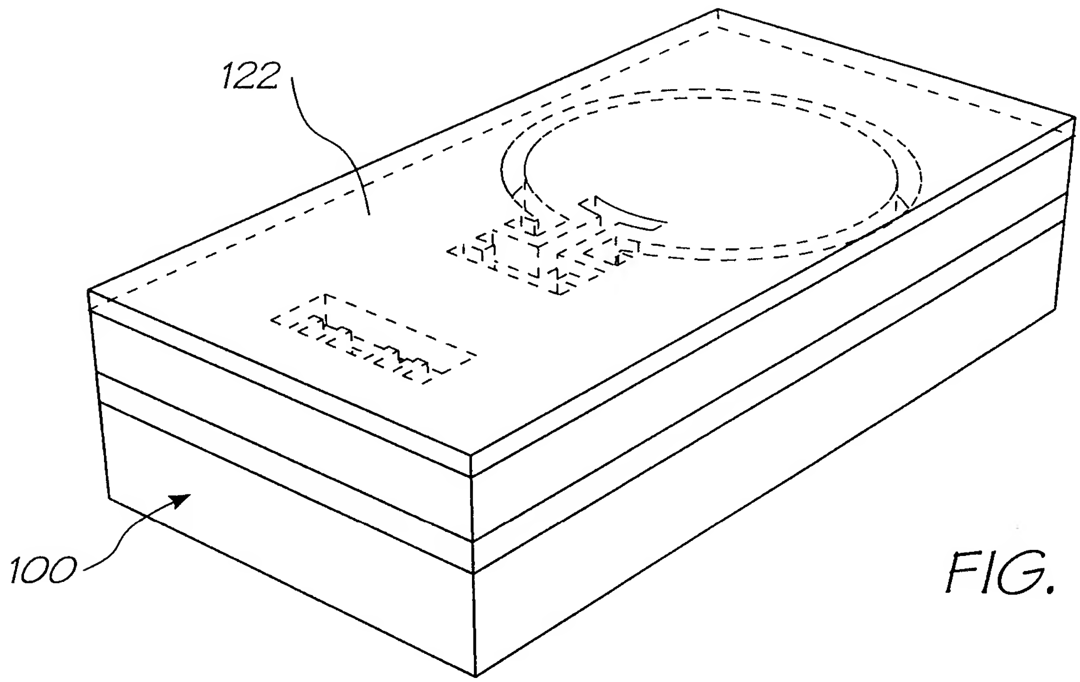
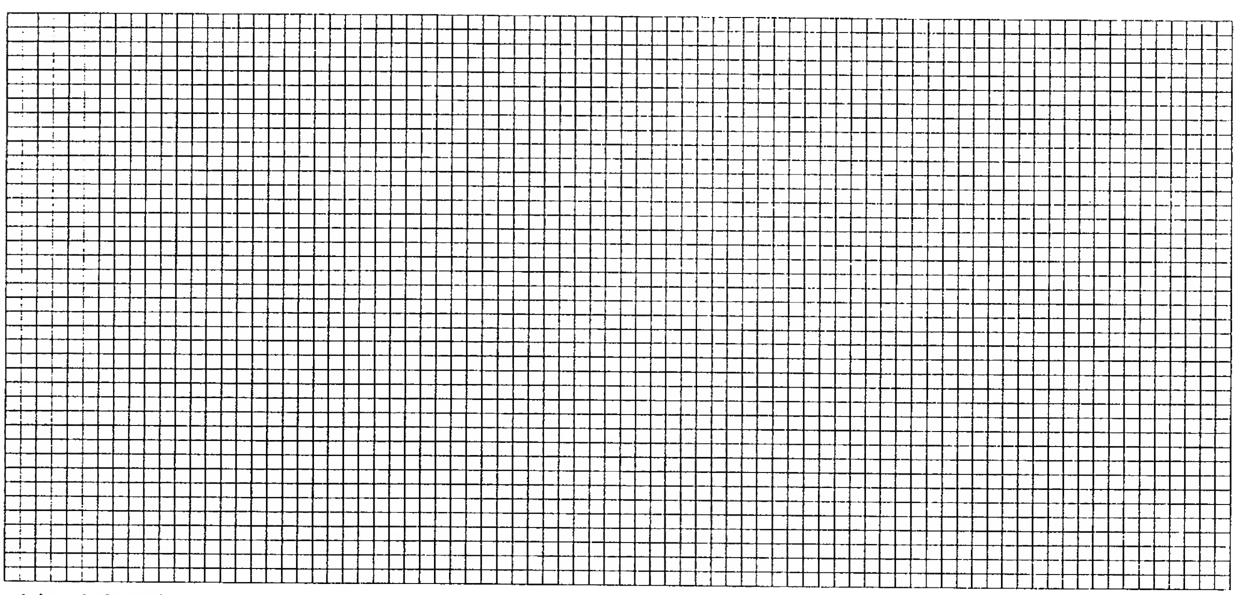
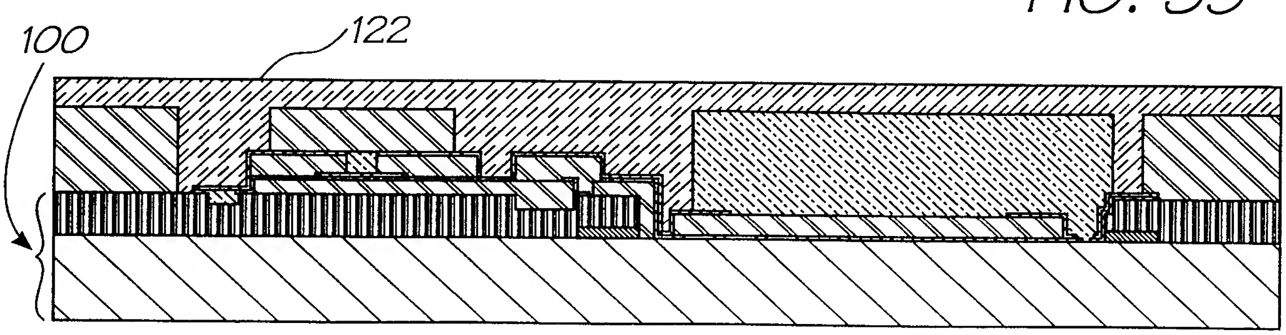


FIG. 34



No Mask

FIG. 35



2 microns conformal PECVD $Si_xN_yH_z$

FIG. 36

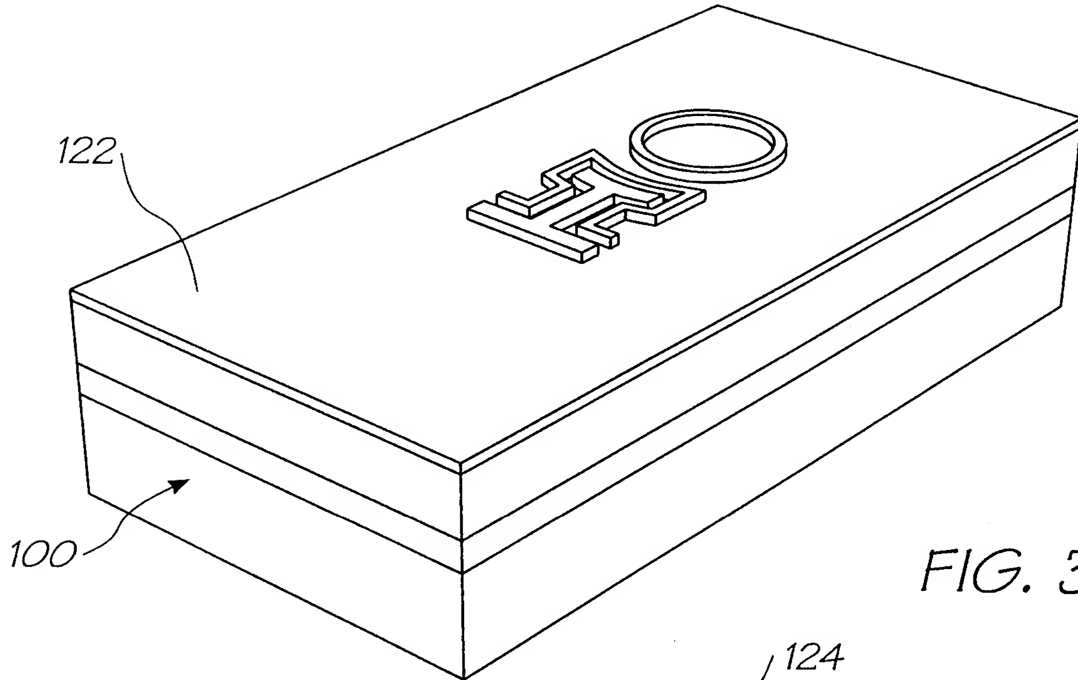
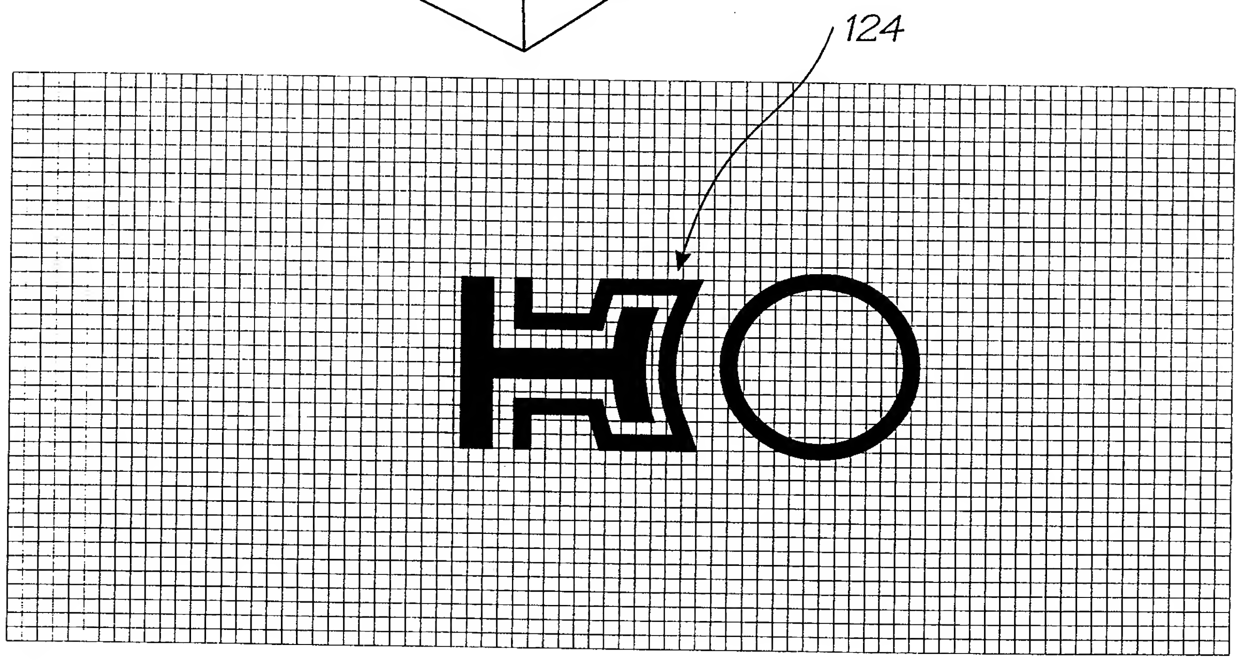
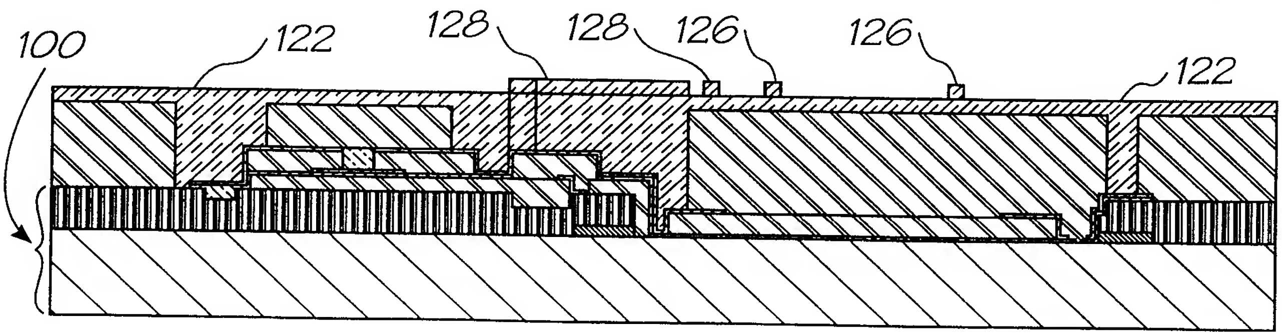


FIG. 37



Mask

FIG. 38



1 micron nozzle tip etch of $Si_xN_yH_z$

FIG. 39

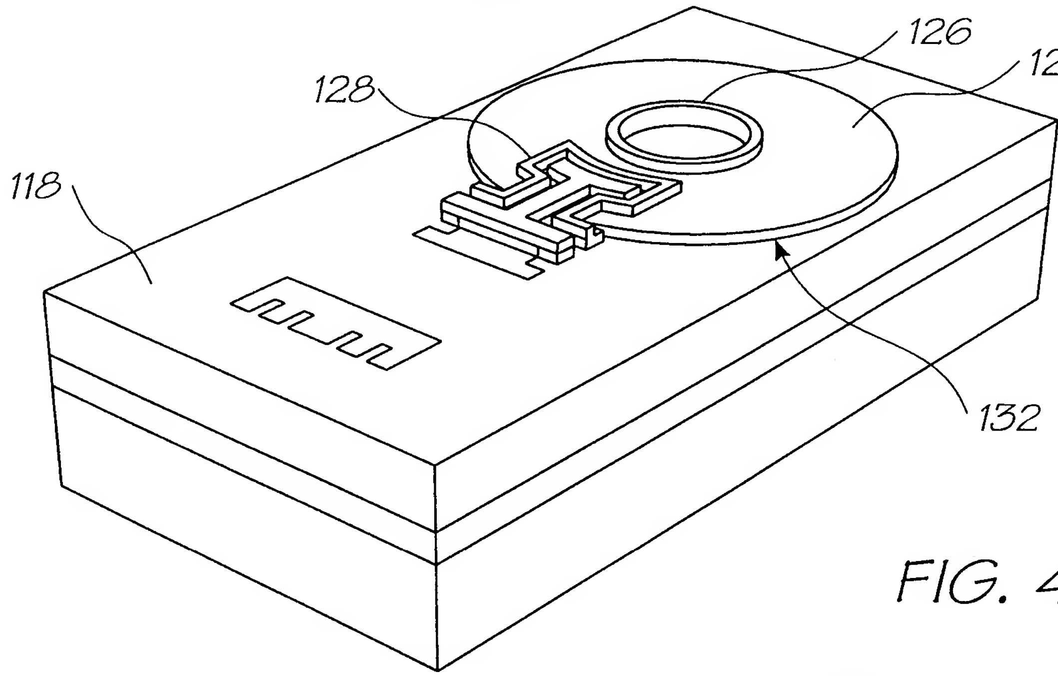


FIG. 40

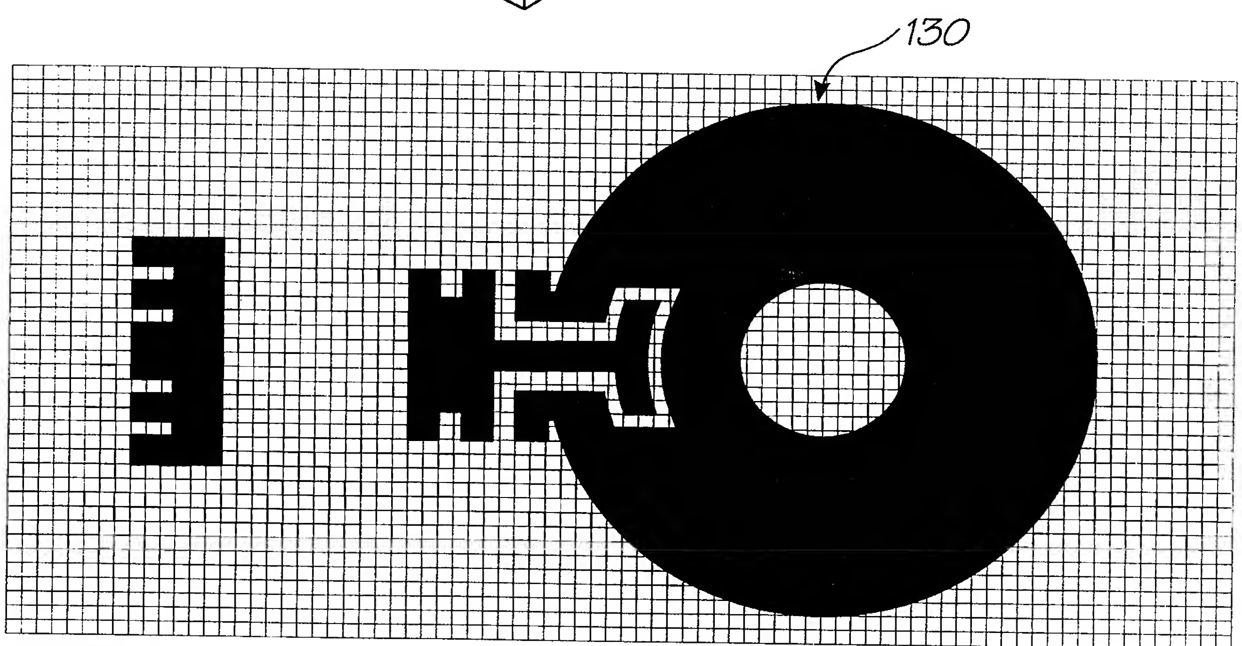
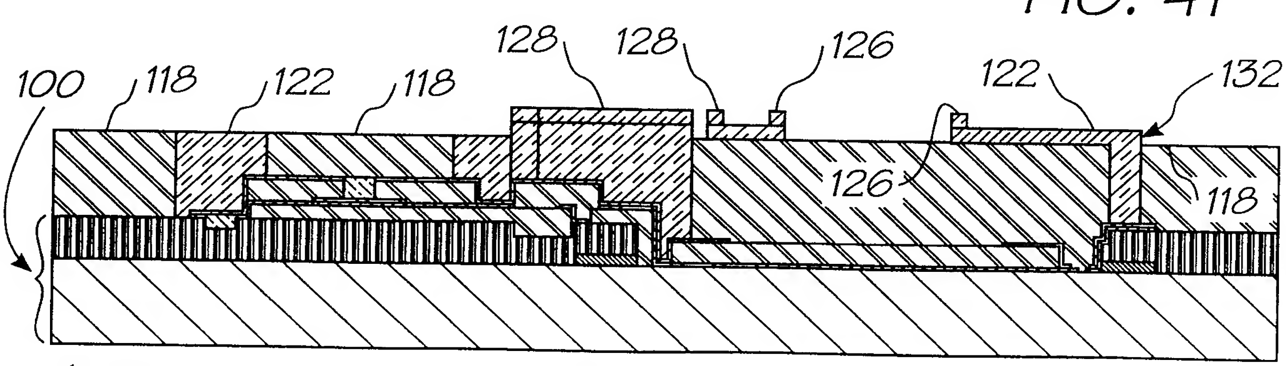


FIG. 41



1 micron nozzle roof etch of $Si_xN_yH_z$

FIG. 42

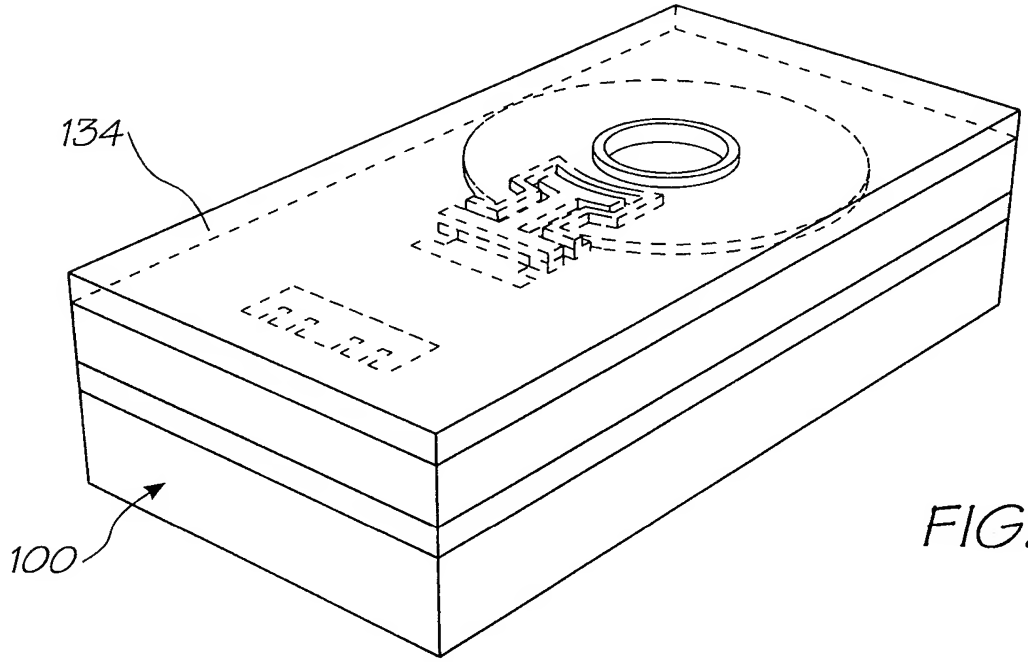
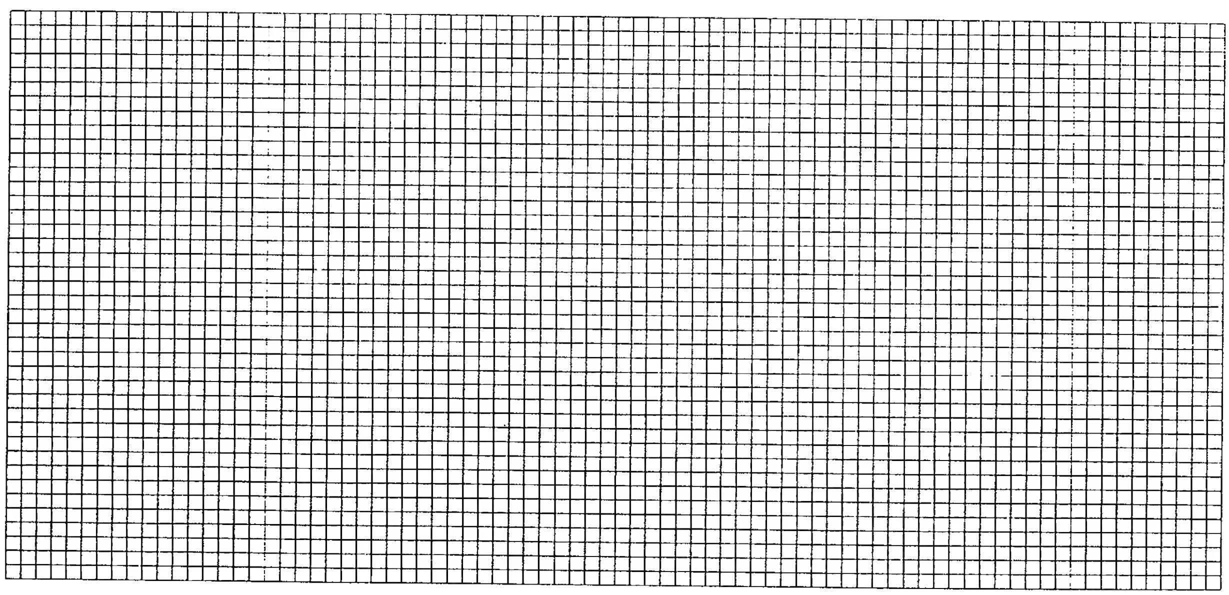
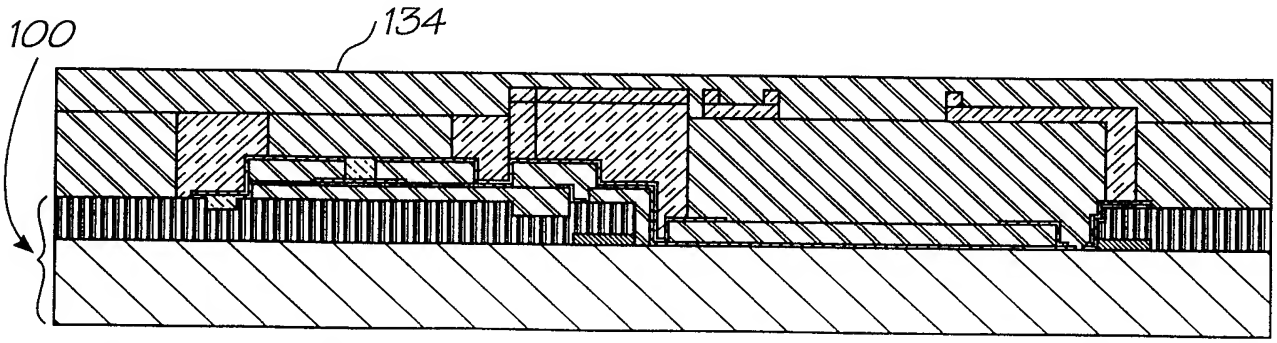


FIG. 43



No Mask

FIG. 44



3 micron sacrificial protective polyimide

FIG. 45

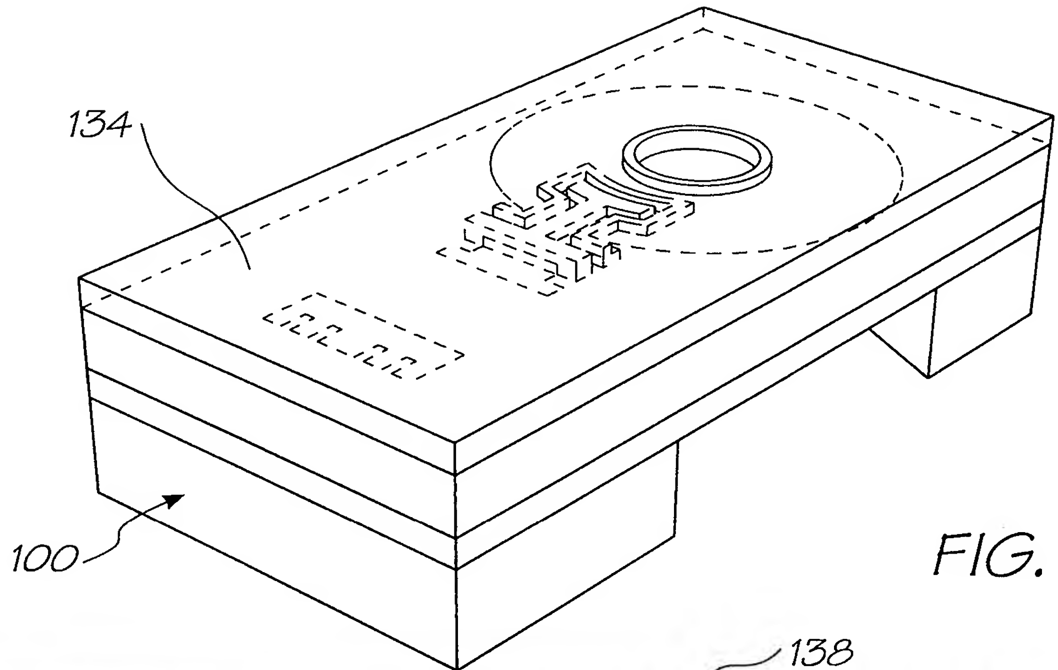
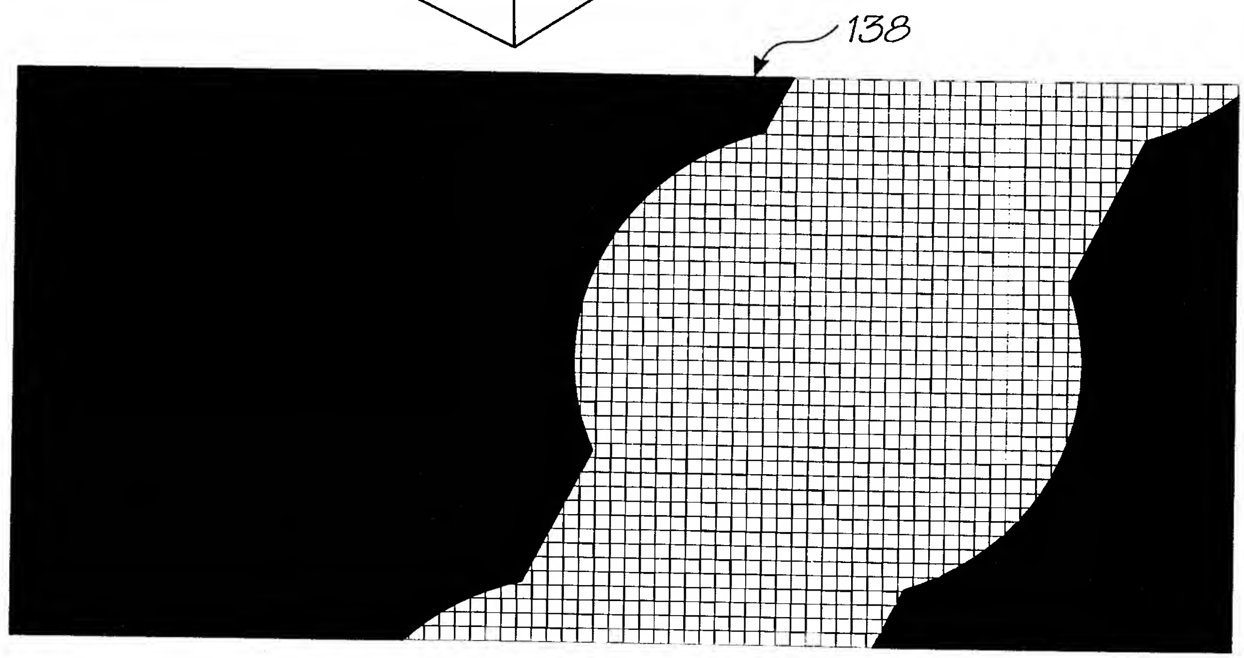
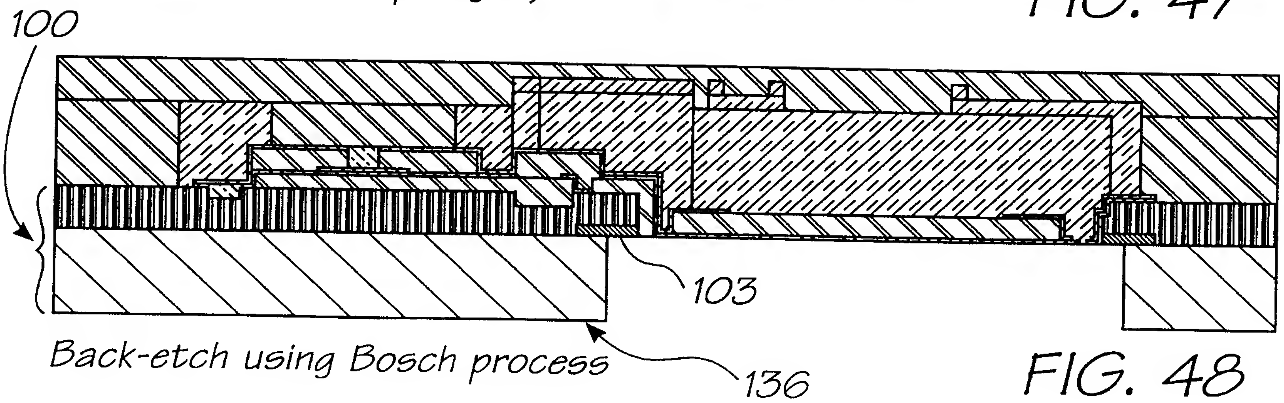


FIG. 46



Mask (includes chip edges)

FIG. 47



Back-etch using Bosch process

FIG. 48

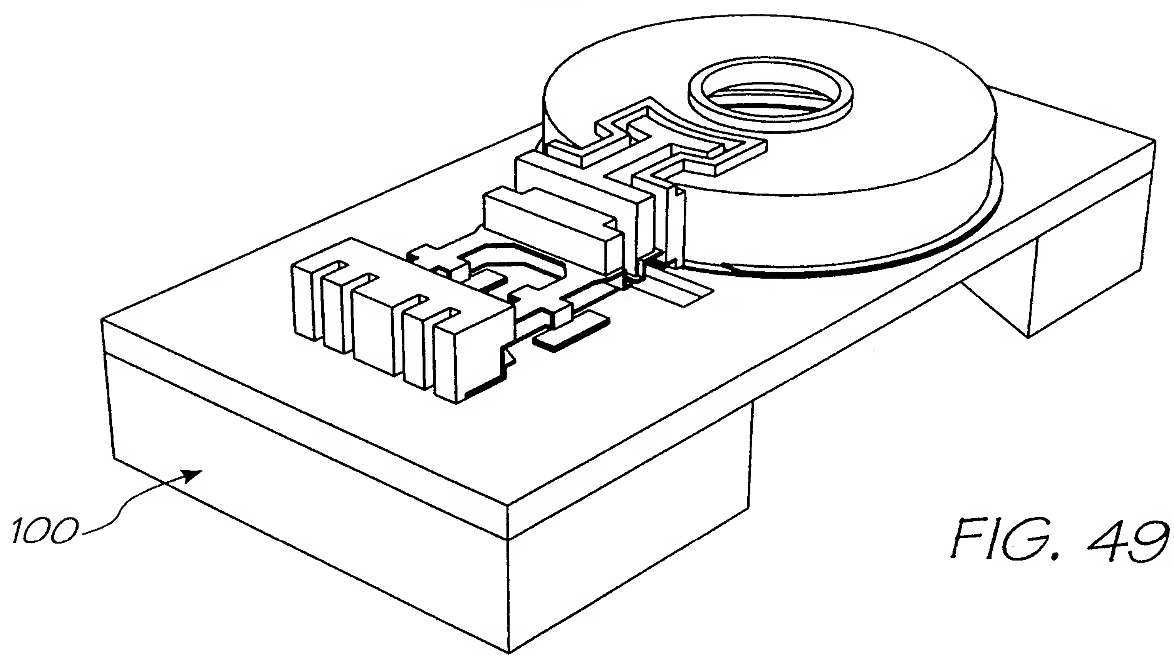
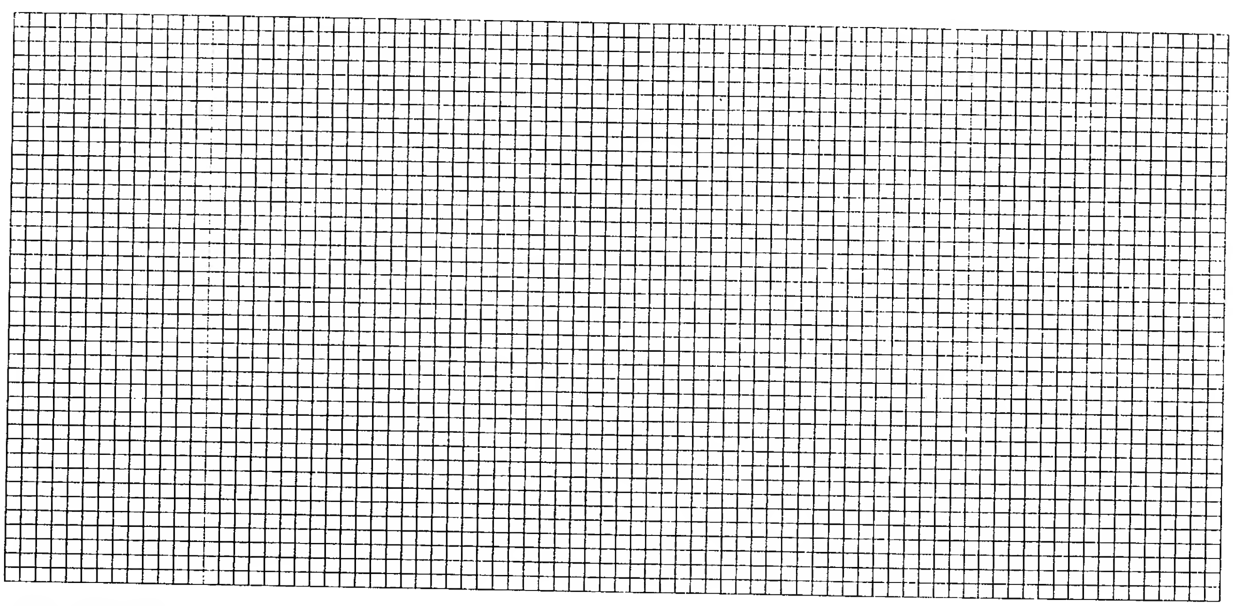
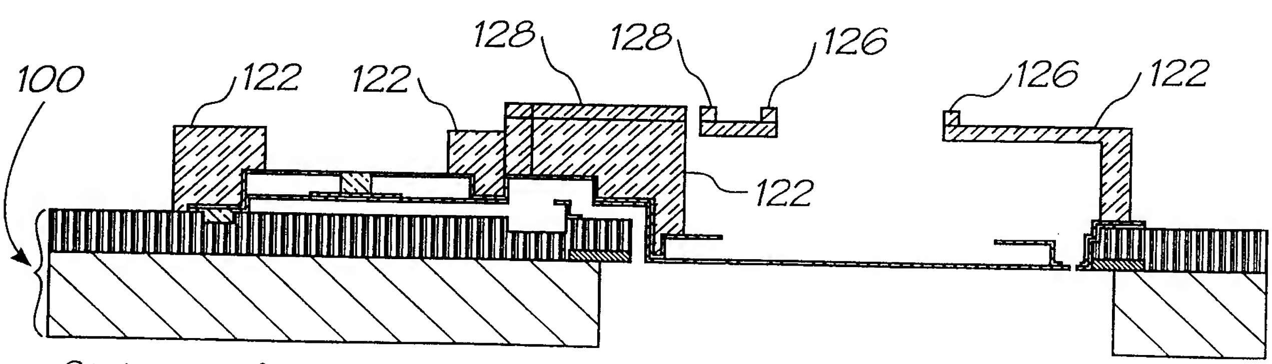


FIG. 49



No Mask

FIG. 50



Strip sacrificial material

FIG. 51

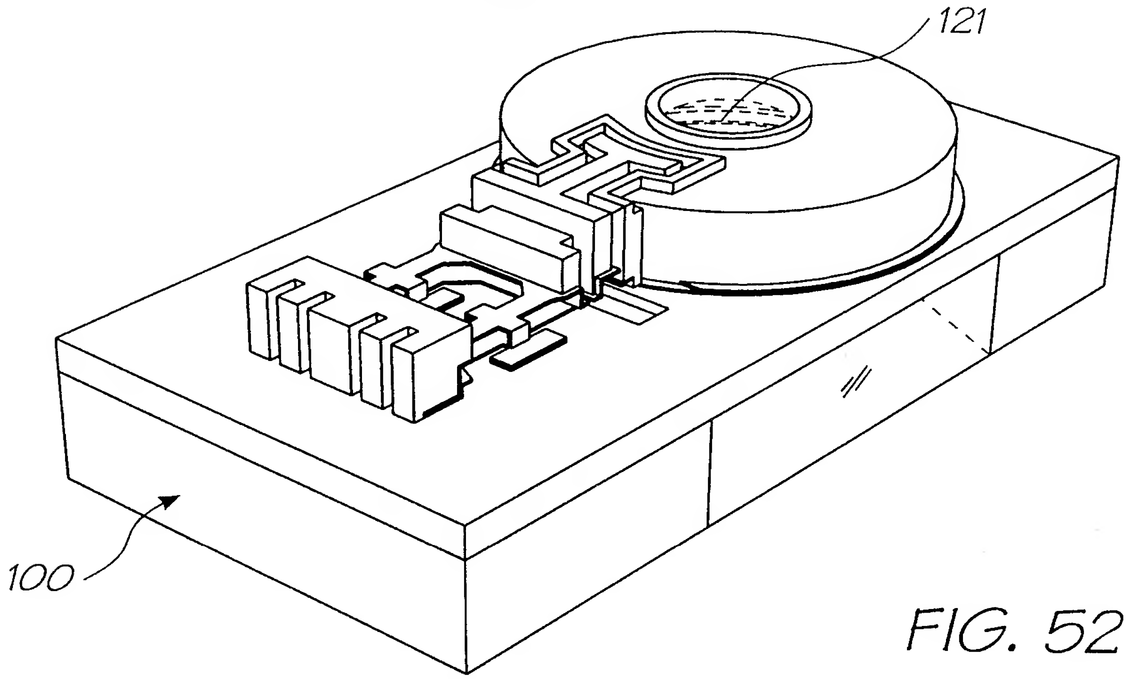
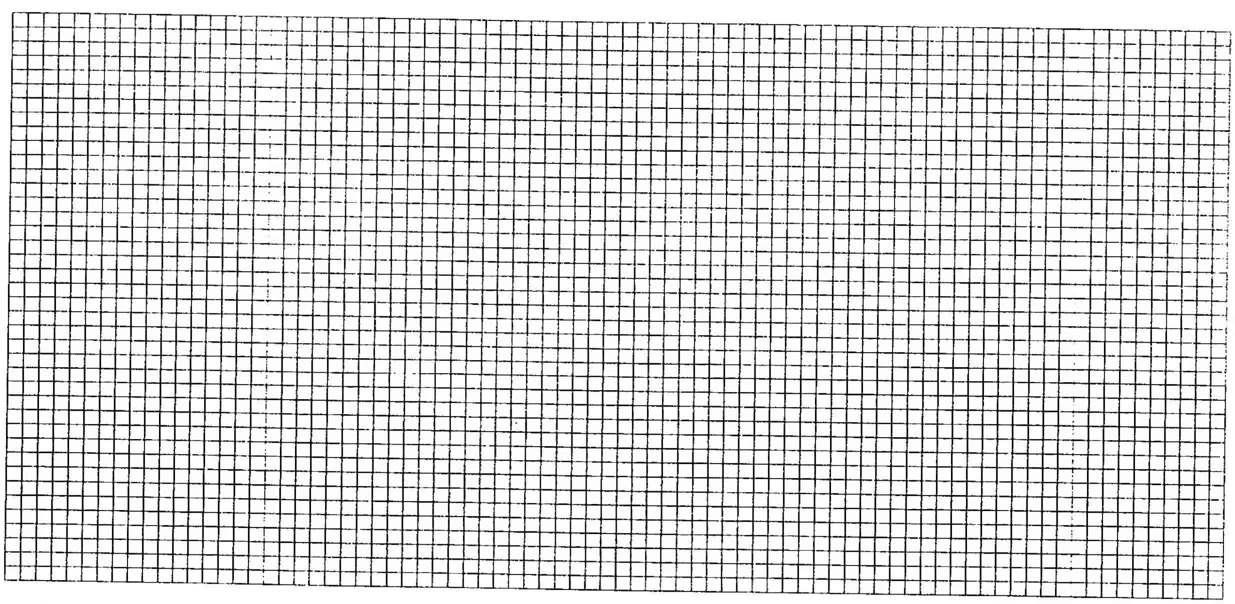
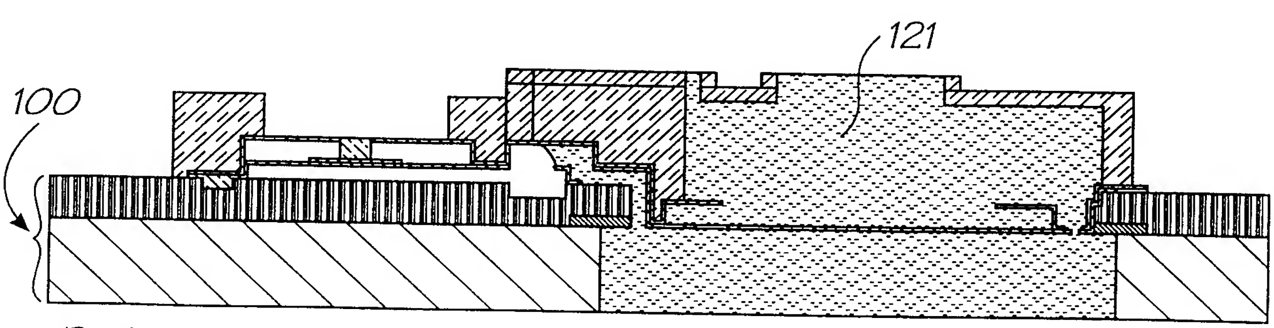


FIG. 52



No Mask

FIG. 53



Package, bond, prime, and test

FIG. 54

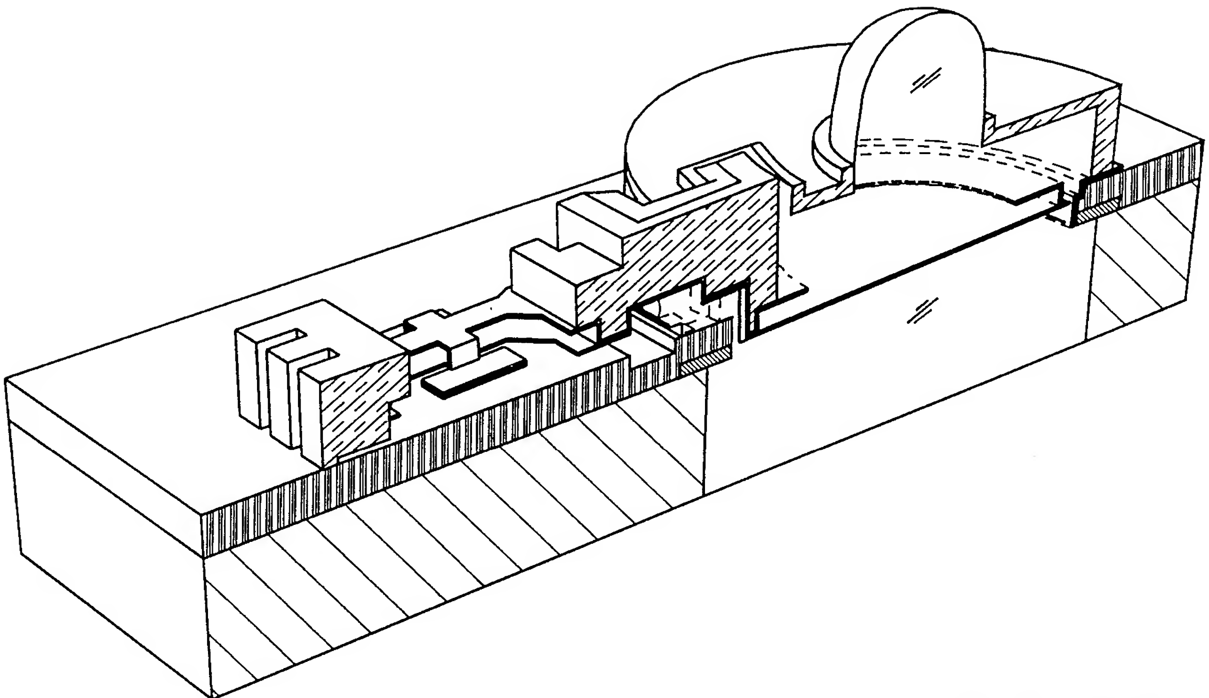
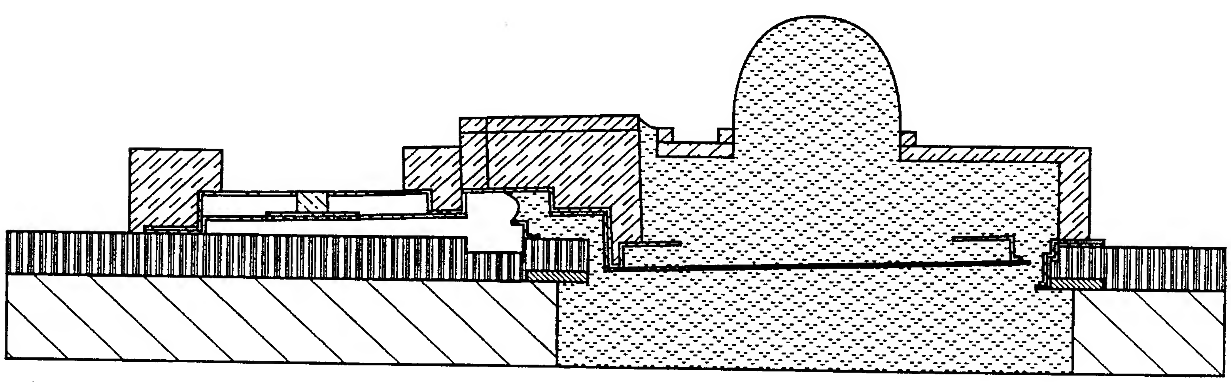


FIG. 55



Actuate

FIG. 56

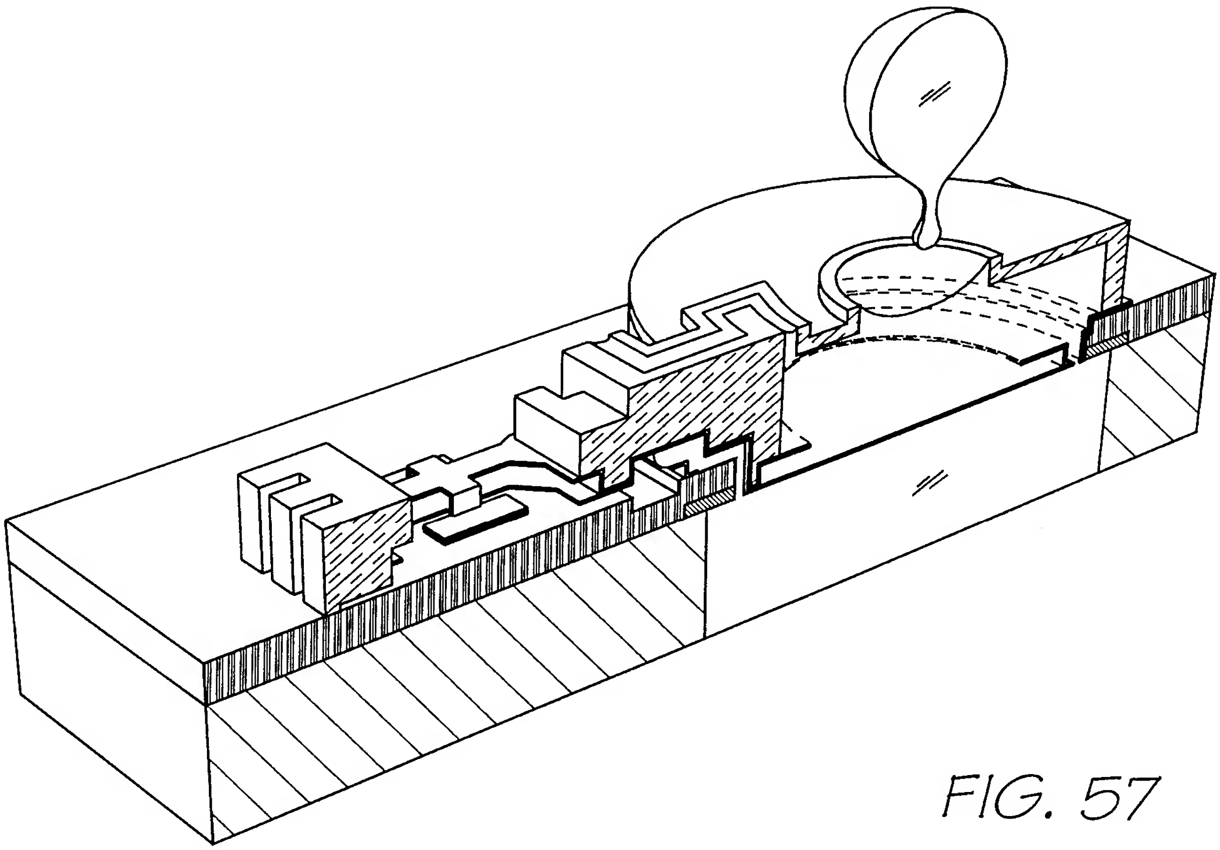


FIG. 57

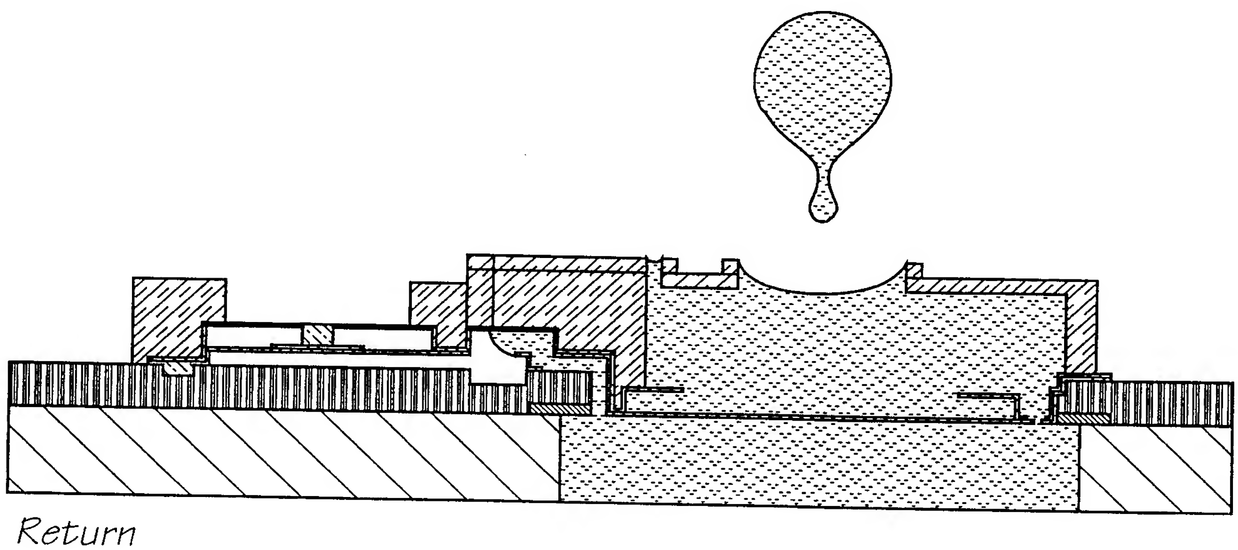


FIG. 58

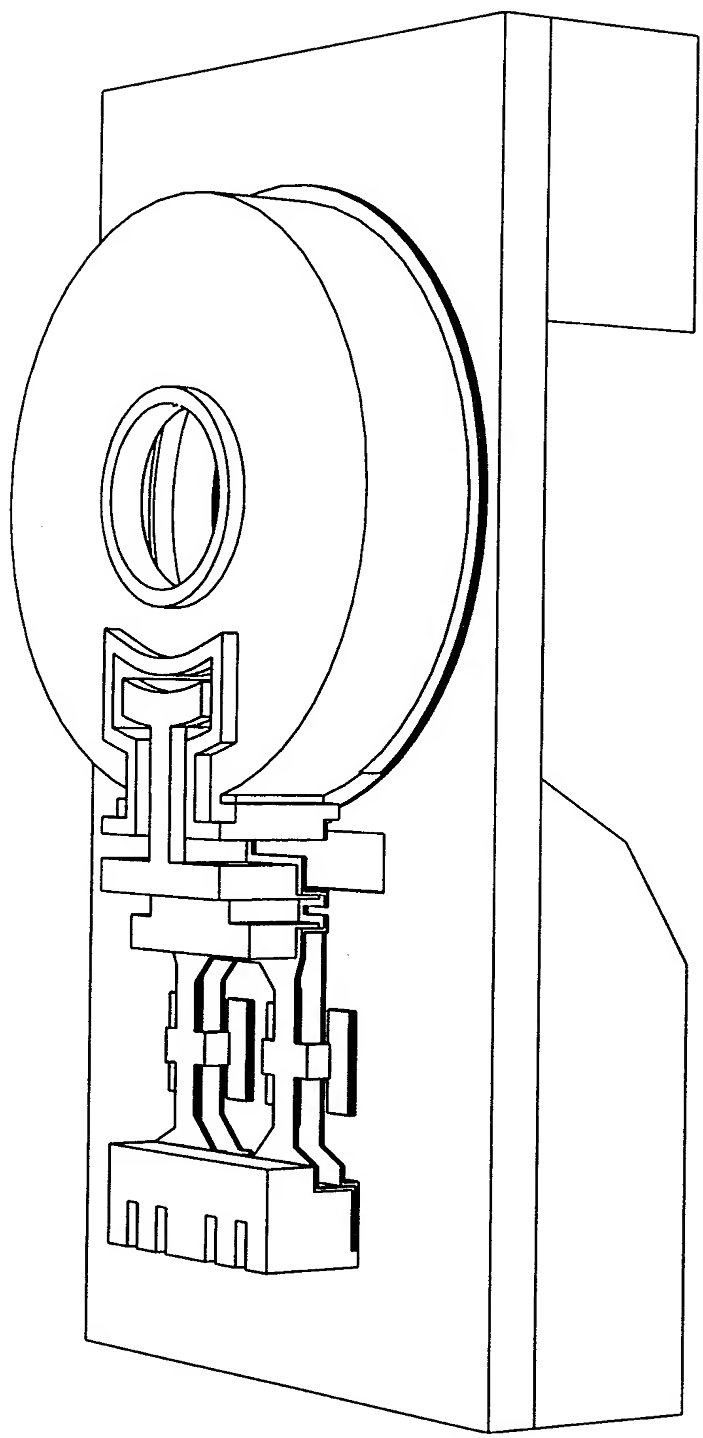


FIG. 59

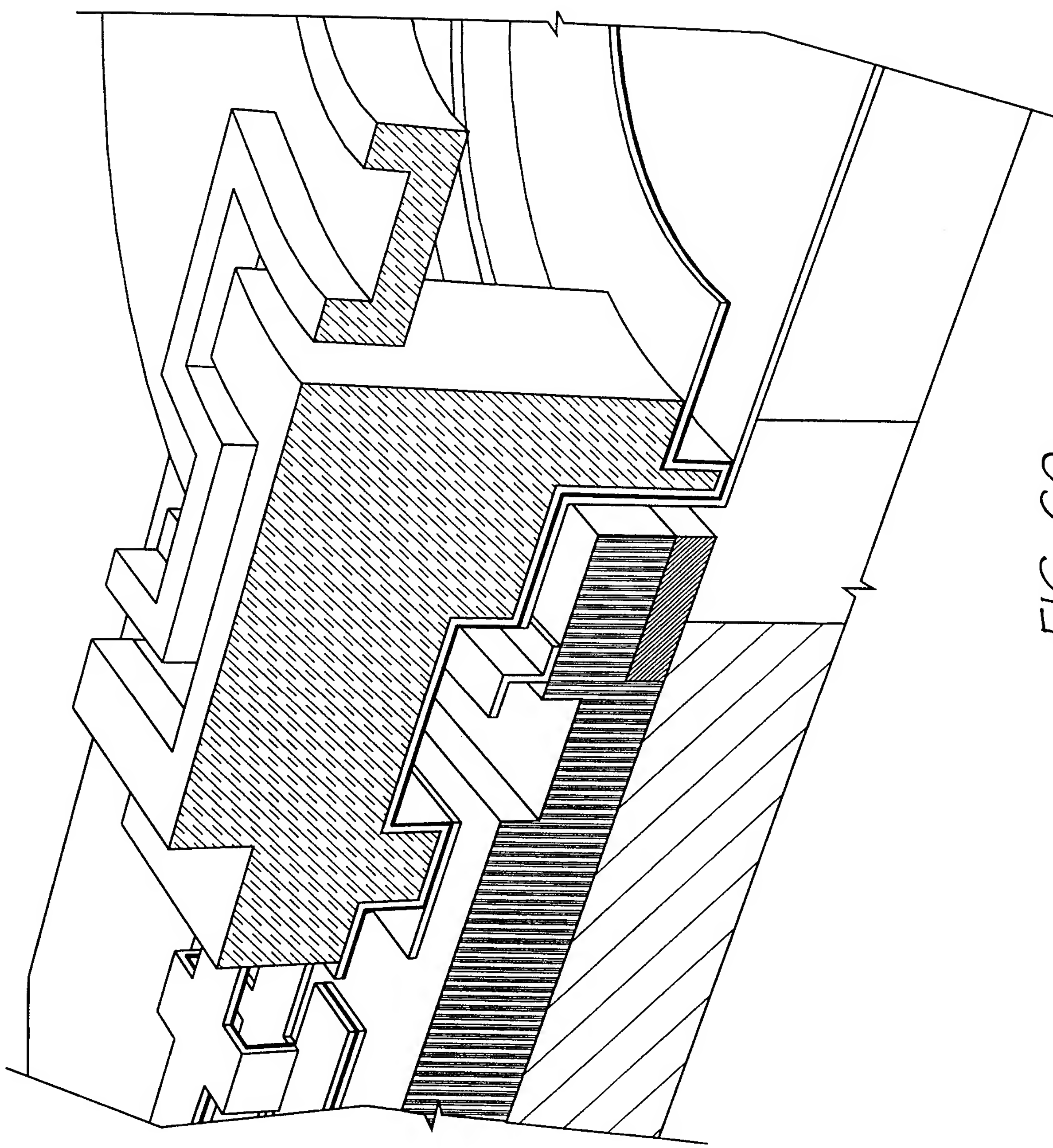


FIG. 60

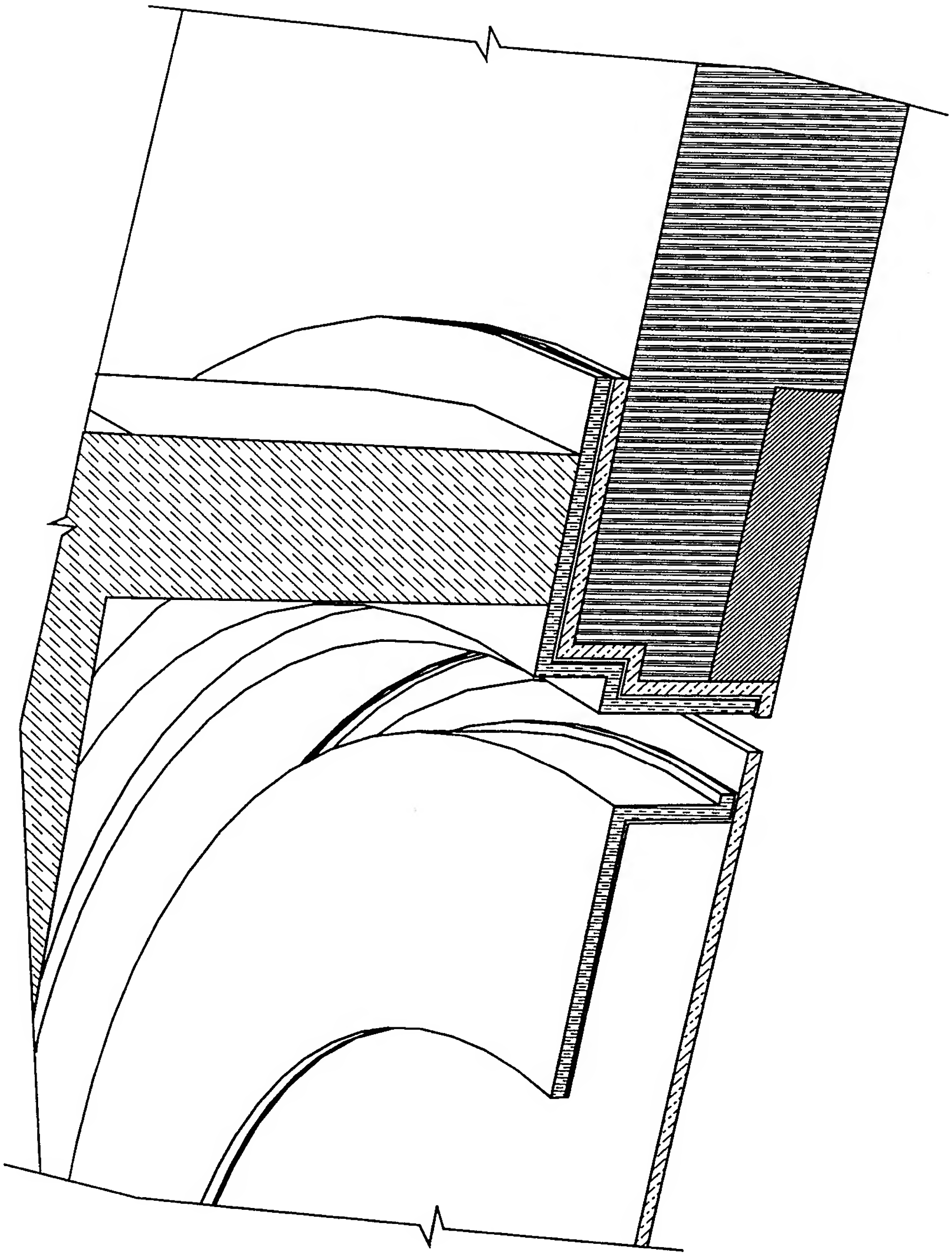


FIG. 61

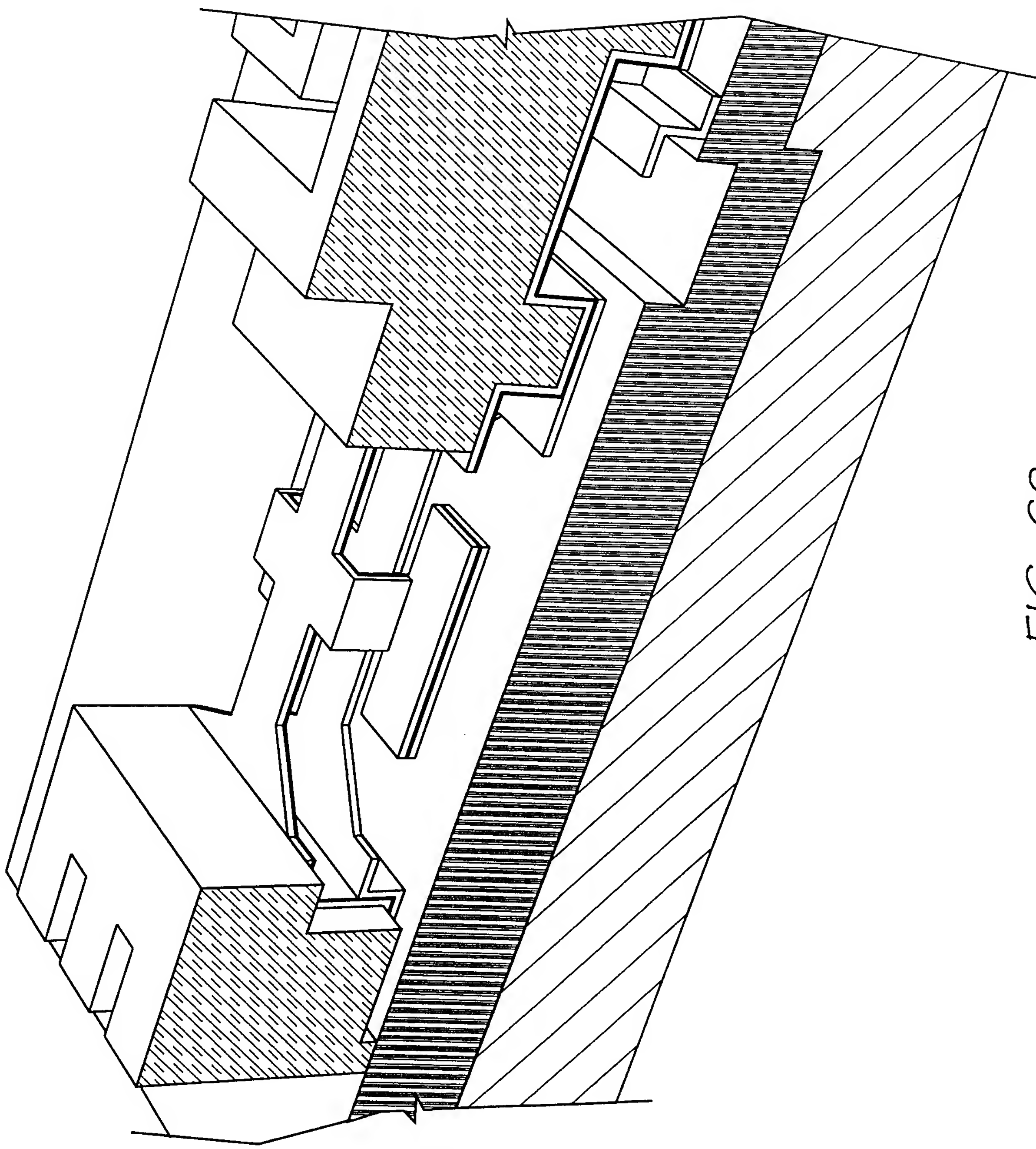


FIG. 62

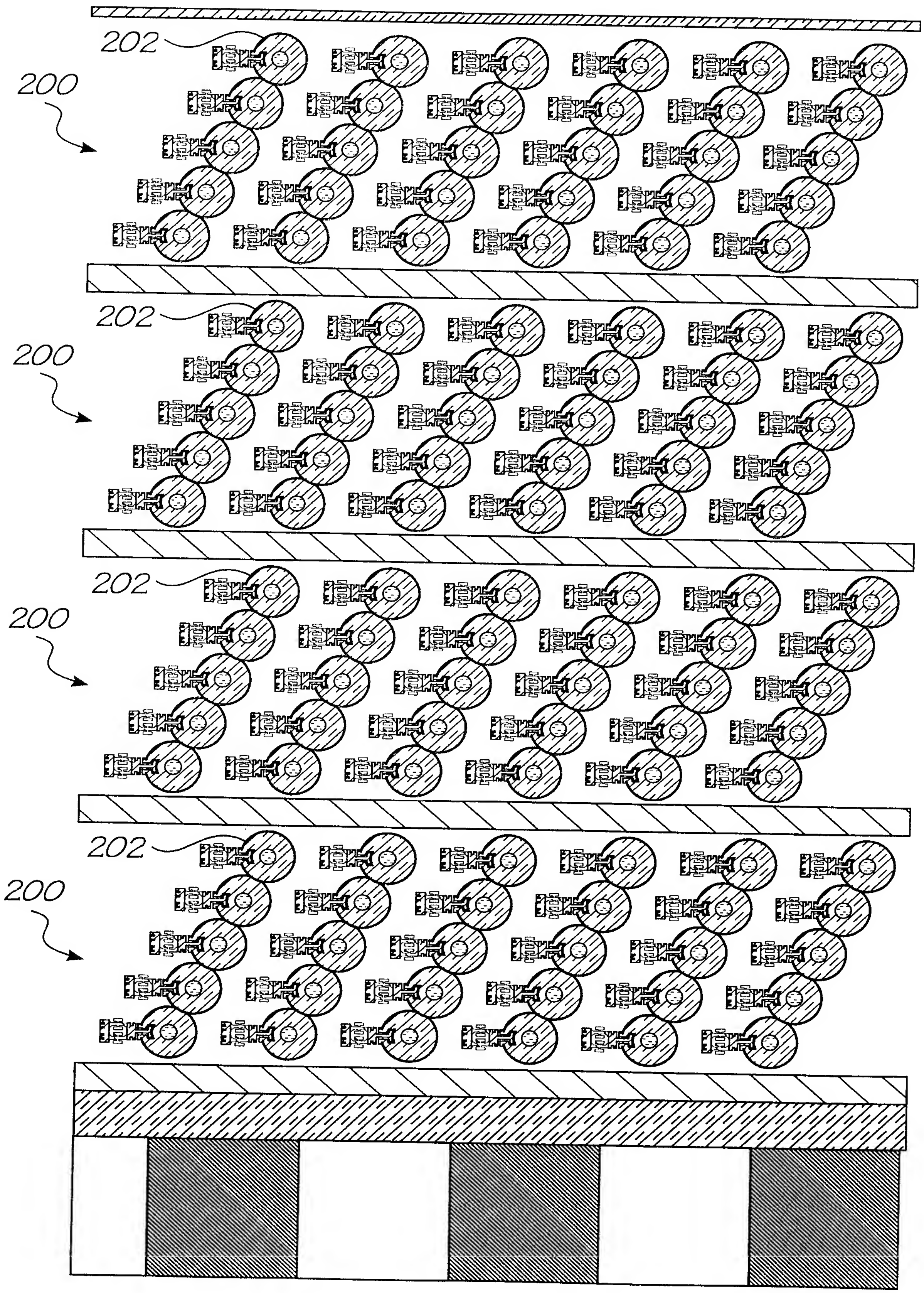


FIG. 63

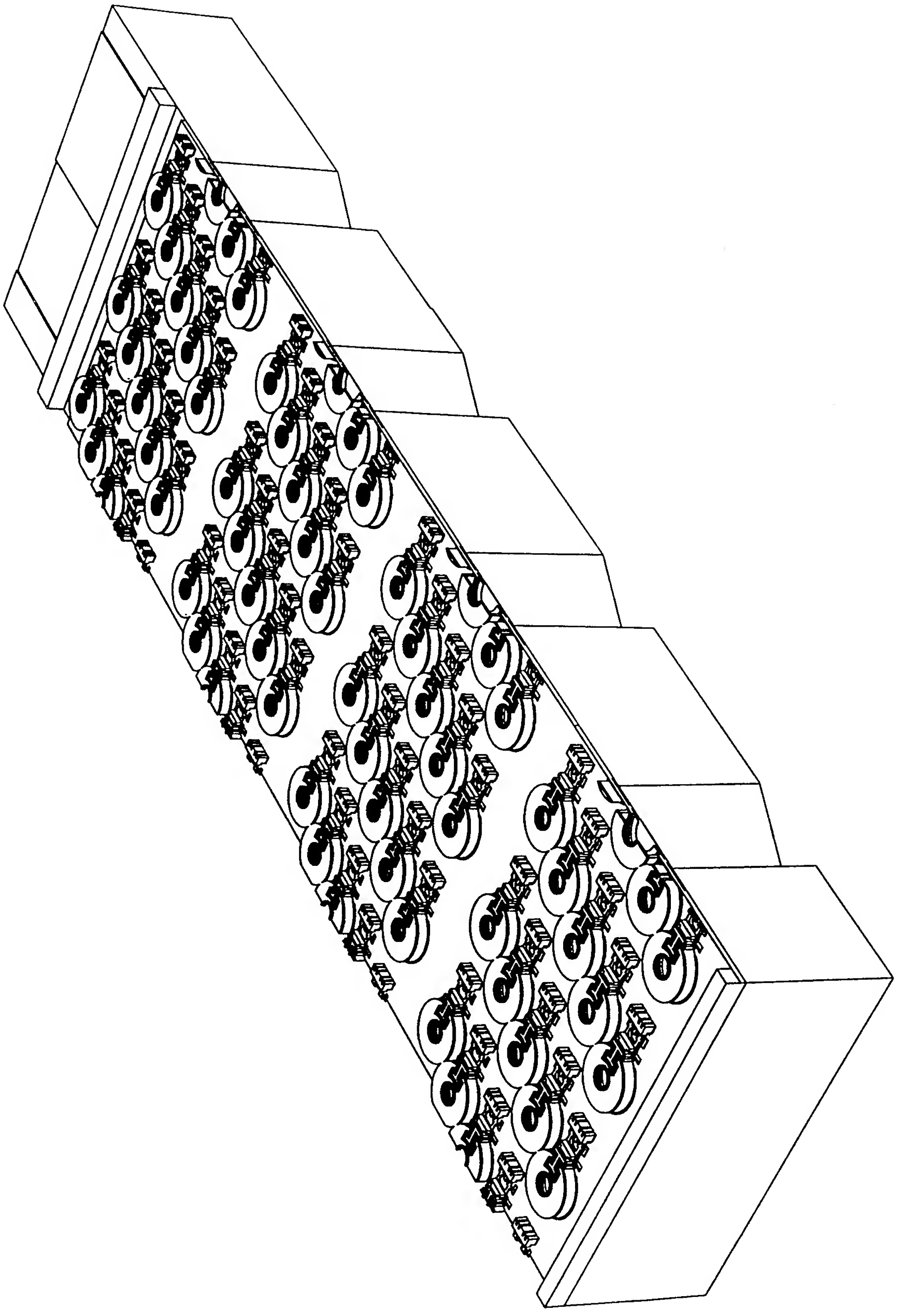


FIG. 64

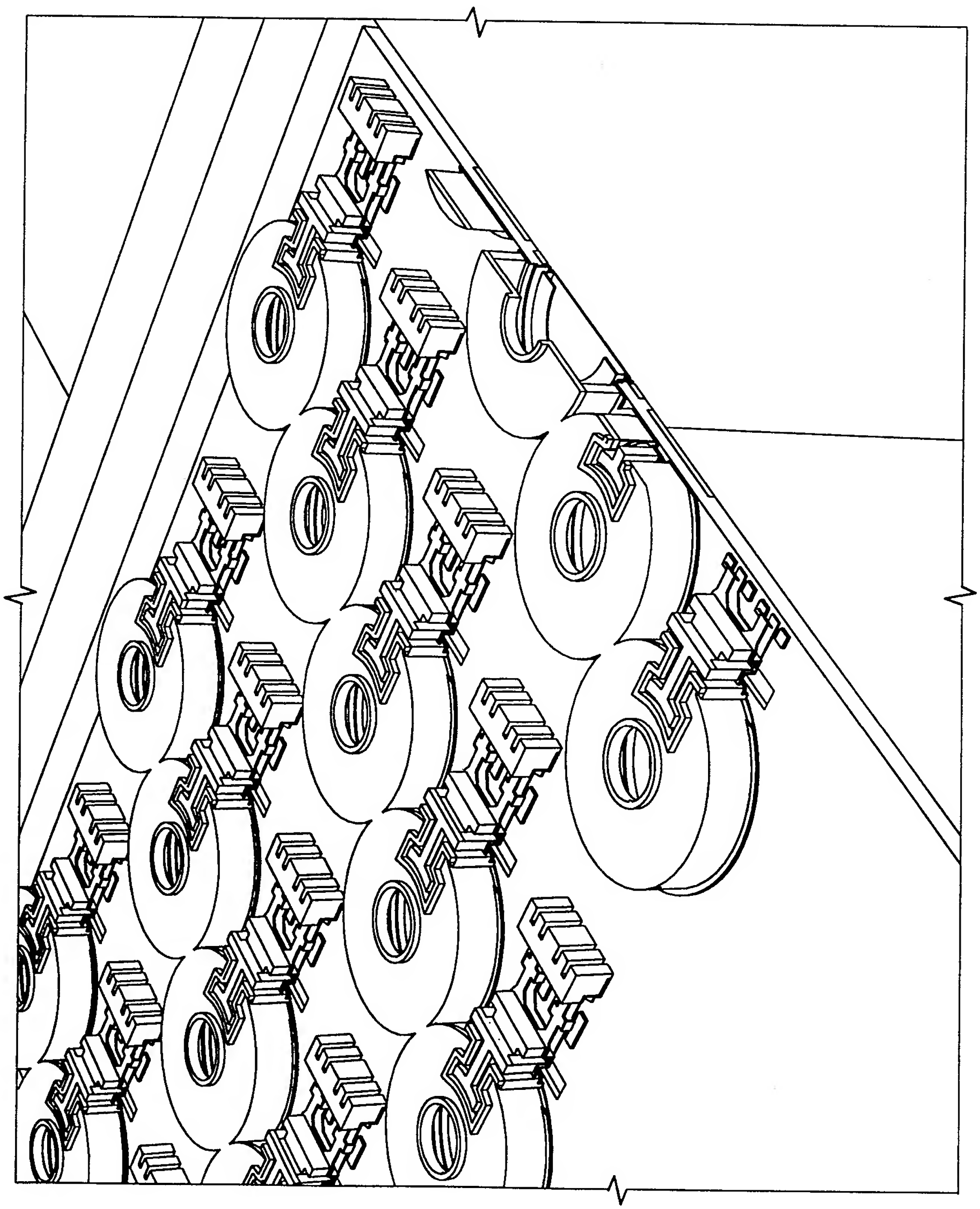


FIG. 65

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU00/00095

A.	**CLASSIFICATION OF SUBJECT MATTER**
Int. Cl. 7:	B81B 3/00, 7/02, B81C 1/00, B41J 2/045, 2/14, 2/16

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: B81B, B81C, B41J 2/-, F03G 7/08, F16K 31/-, G12B 1/00, 1/02, B05B 1/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DWPI
JAPIO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 99/03681 A (SILVERBROOK RESEARCH PTY. LIMITED) 28 January 1999 Pages 46-48, Figures 1-19	1-8
X	US 5058856 A (GORDON ET AL.) 22 October 1991 Columns 2-6, Figures 1-3	1-3, 6

☐ Further documents are listed in the continuation of Box C ☒ See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 April 2000	- 9 MAY 2000
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized officer **MICHAEL HALL** Telephone No : (02) 6283 2474

Box 1 **Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos :

because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos :

because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos :

because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box II **Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

1.	Claims 1-8, 15-40	Thermal actuator with gap between two arms
2.	Claims 9-14	Ejection paddle with structural support portion acting as spacer from nozzle
3.	Claims 41-48	Aperture in nozzle chamber with raised rim for forming meniscus with actuator arm
4.	Claims 49-53	Nozzle chamber with internal protrusion aligning with ejection paddle

as reasoned on the extra sheet.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

   1-8, 15-40

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

Supplemental Box
(To be used when the space in any of Boxes I to VIII is not sufficient)

Continuation of Box No: II

The international application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept. In coming to this conclusion the International Searching Authority has found that there are different inventions as follows:

1. Claims 1-8, 15-40 directed to an actuator for micro mechanical or micro mechanical devices, comprising two arms spaced apart from each other to form a gap between them, where one arm is arranged to undergo thermal expansion to cause the actuator to apply a force. It is considered that having a gap between the arms comprises a first “special technical feature”. This feature in particular gives advantages of improving operational characteristics of the actuator, reducing shear stress, lowering the chance of delamination, and providing greater energy efficiency, as noted at page 2 lines 6-21 and page 13 lines 6-15 of the specification.

2. Claims 9-14 directed to a paddle for ejecting liquid from a nozzle chamber, comprising a plunger surface opposite to and spaced from the nozzle, and a structural support portion formed on the periphery of the plunger surface which acts as a spacer for preventing the plunger surface from reaching the nozzle. It is considered that a structural support portion acting as a spacer between the plunger surface and the nozzle comprises a second “special technical feature”. This feature in particular reduces the chance of contact between the plunger surface and a meniscus at the nozzle, and allows the nozzle chamber size to be reduced, as noted at page 3 line 16-22 and page 12 lines 3-9 of the specification.

3. Claims 41-48 directed to a liquid ejection device with an aperture through which an actuator arm is connected to a paddle, for ejecting liquid through a nozzle, where a raised rim is formed around the aperture such that in operation a meniscus is formed between the raised rim and the actuator arm. It is considered that the raised rim for forming a meniscus with the actuator arm comprises a third "special technical feature". This feature in particular prevents liquid spreading out through the aperture, as noted at page 6 lines 20-31 and page 12 lines 9-11 of the specification.

4. Claims 49-53 directed to a liquid ejection device with a paddle in a nozzle chamber for ejecting liquid, where the paddle aligns with an internal protrusion of the nozzle chamber to close a liquid supply port when in a non-ejection state, and becomes spaced from the protrusion to form a liquid refill channel when in an ejection state. It is considered that the internal protrusion aligned with the paddle in its non-ejection state comprises a fourth "special technical feature". This feature in particular permits rapid refill of the nozzle chamber after ejection, as noted at page 11 line 28 to page 12 line 2 of the specification.

It should be noted that while the latter three groups of claims above share the feature of a paddle in a nozzle chamber, this feature is known from prior art [eg, page 1 lines 25-30 of the specification, and WO 99/03681 A (SILVERBROOK RESEARCH PTY LIMITED) 28 January 1999], and hence is not a "special technical feature" as defined in PCT Rule 13.2.

Since the abovementioned groups of claims do not share any of the technical features identified, a “technical relationship” between the inventions, as defined in PCT rule 13.2 does not exist. Accordingly the international application does not relate to one invention or to a single inventive concept, a priori.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/AU00/00095

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
WO	9903681	AU	83227/98	AU	83235/98	AU	83236/98
		AU	83238/98	WO	9903680	WO	9904368
		WO	9904551				
US	5058856	EP	512521	JP	5187574		

END OF ANNEX